

**HIGH-TEMPERATURE FLUID-WALL  
REACTOR TECHNOLOGY  
RESEARCH, TEST AND  
EVALUATION PERFORMED AT  
NAVAL CONSTRUCTION  
BATTALION CENTER  
GULFPORT, MS, FOR THE USAF  
INSTALLATION/RESTORATION  
PROGRAM**

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The objective of this effort was to examine the feasibility of using a thermal-pyrolysis technology to treat Herbicide Orange (HO)-contaminated soil at the Naval Construction Battalion Center, (NCBC) Gulfport MS. A field demonstration of a pilot-scale unit provided the technical evaluation and cost estimates for comparison with other cleanup technologies. The J.M. Huber Advanced Electric Reactor (AER), a high-temperature fluid wall reactor, was used to successfully treat 1100 pounds of soil contaminated with Herbicide Orange and 2,3,7,8-tetrachlorobenzo-p-dioxin (TCDD). The AER process pyrolysis organics at a temperature of 3600 to 4100 degrees F. under a nitrogen atmosphere to prevent combustion. After AER testing was completed, samples of the NCBC feedstock and test-treated soil were sent to two laboratories for analysis. Based on two composite samples, analysis of feedstock showed 2,3,7,8-TCDD levels of 111 and 193 parts per billion (ppb). Concentrations in the treated soil for the sum of all dioxin/furan congeners was less than 1 ppb, the Air Force test criterion. The AER process demonstrated the (Cont'd. on reverse.					
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capability to treat dioxin-contaminated soil and may be considered for full-scale soil restoration at USAF HC sites. Sensitivity analyses of six variables (geographic location, soil quantity, electrical power prices, labor, capital equipment use charge and transportation) were performed to estimate cost for conditions other than those found at NCBC. The process may have application for treatment of more easily pyrolyzed organic compounds such as semivolatiles, pesticides, and polychlorinated biphenyls, as well as some inorganics.

This report is organized into two volumes: Volume I presents the final report on the performance of an advanced electric reactor for use in decontaminating soil containing Herbicide Orange. Volume II presents supplementary analytical data and historical information that supports the the research findings reported in the first volume.

## SUMMARY

In June 1985, the J. M. Huber Advanced Electric Reactor (AER) mobile pilot plant (AER3), a high-temperature fluid wall reactor, was used to successfully treat 1100 pounds of soil contaminated with 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) at the Naval Construction Battalion Center (NCBC) in Gulfport, Mississippi. The contamination resulted from earlier spills at a Herbicide Orange storage area at NCBC. The mobility of this pilot plant provided a quick and inexpensive means of demonstrating AER technology under field conditions as part of the research, test, and evaluation phase of the U.S. Air Force Installation Restoration Program.

The AER process, which operates in a nitrogen atmosphere at a temperature of 3600 to 4100 °F, destroys dioxins, furans, and other organic compounds by pyrolysis. The AER3 is lined with electrode-heated graphite, which has an inside diameter of 3 inches and a heated length of 36 inches. Screw-fed soil feedstock falls by gravity flow through the reactor, and the treated soil is collected in an enclosed bin. A gaseous blanket of nitrogen separates the graphite from the reactants. Gas effluent is passed through a particulate filter and two activated carbon filters before emission from a stack.

After AER demonstration testing was completed, samples of the NCBC feedstock and test-treated soil were sent to two laboratories for analysis of dioxin concentrations. Although third-party verification analytical data could not be validated according to U.S. Environmental Protection Agency (EPA) Contractor Laboratory Program practices, the data were useful to evaluate the effectiveness of the AER process technology.

NCBC soil feedstock was analyzed and found to contain 193 and 111 ppb of 2,3,7,8-TCDD, respectively, based on two composite samples. Treated soil was analyzed and found to have a total dioxin/furan concentration of less than 1 ppb, which met test criteria.

Analytical results provided by Battelle Columbus Laboratories showed the sum of the total isomer detection limit values (DLVs) for tetra-, penta-, and hexachlorodibenzo-p-dioxins and tetra-, penta-, and hexachlorodibenzofurans to be 0.12 ppb, with a DLV for 2,3,7,8-TCDD of 0.04 ppb.

By comparison, analytical results obtained from California Analytical Laboratories showed the sum of the indication or DLV for the six isomer classes to be 0.35 ppb. The isomer 2,3,7,8-TCDF was detected at a concentration of 0.028 ppb; whereas, 2,3,7,8-TCDD was not detected at a DLV of 0.036 ppb. Semivolatile organic compounds, 2,4,5/2,4,6-trichlorophenol and 2,4-dichlorophenol, present in the feedstock were also destroyed to levels less than detectable (1 ppm). Inorganic concentrations of the treated soil were sufficiently low to be not considered hazardous according to the EPA delisting criteria. Because the AER3 test operating temperature was 3650 °F, inorganics, especially lead and zinc, were volatilized from the soil. They were then transported in the exhaust stream and collected in a baghouse filter. Five priority pollutant semivolatile organics not detected in either the feedstock or treated soil were detected in the baghouse filter material. It is suspected that these organics were the result of recombination of reactants in the lower part of the heated zone where there was insufficient residence time for their destruction.

Restoration of contaminated soil at NCBC could be accomplished by using a full-scale AER (e.g., core diameter of 18 inches and length of 18 feet) transported to and assembled in the field. A cost estimate of \$14.3 million for treatment of 20,000 tons ( $18,800 \text{ yd}^3$ ) of TCDD-contaminated soil using the NCBC site as a reference case has been prepared. The unit cost is \$716/metric ton ( $\$762/\text{yd}^3$ ). This includes soil excavation, transportation, soil pretreatment, AER treatment, and return of treated soil to the excavated area. Estimated time to perform site installation, soil treatment, and site teardown is 62 weeks. Sensitivity analyses of six variables (geographic location, soil quantity,

electrical power prices, labor, capital equipment use charge, and transportation) have been conducted to provide data for conditions other than those used in the reference case, with soil quantity found to be the most significant.

The AER process demonstrated the capability to treat dioxin-contaminated soil to meet Air Force test criteria, and may be considered for full-scale soil restoration of dioxin-furan contaminated soils. Its application is also suitable for treatment of other more easily pyrolyzed organic compounds, such as semivolatiles, pesticides, and polychlorinated biphenols, requiring treatment to meet EPA criteria.

It is recommended that the AER process be considered for testing of heavy metal-contaminated soils where these elements can be collected during the process and recycled, as well as provide a means of restoring the soil.

It is recommended that anyone considering use of the AER technology should check the EPA regulations for changes subsequent to 1985-86, when the testing and data evaluation occurred, that could impact its use for proposed remedial actions.





## PREFACE

This report was prepared for the Air Force Engineering and Services Center, Engineering and Services Laboratory, Tyndall AFB, Florida, under Job Order Number (JON) 2103 9027. The principal contractor, EG&G Idaho, Inc., is the prime contractor for the Department of Energy, Idaho National Engineering Laboratory. The major subcontractor for the project is the J.M. Huber, Corp., Borger, Texas.

This report is organized into two volumes: Volume I presents the final report on the performance of an advanced electric reactor for use in decontaminating soil containing Herbicide Orange. Volume II presents supplementary analytical data and historical information that supports the the research findings reported in the first volume.

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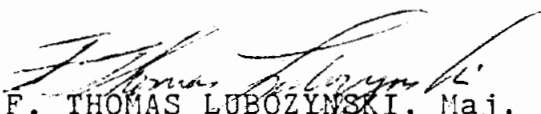
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## SECTION I INTRODUCTION

### A. OBJECTIVE

The objective of this program is to demonstrate the feasibility of using a thermal-pyrolysis technology for soil cleanup and restoration of a Herbicide Orange (HO)-contaminated site at the Naval Construction Battalion Center (NCBC) at Gulfport, Mississippi. This program is under the sponsorship of the Air Force Engineering and Services Center (HQ AFESC), Tyndall Air Force Base, Florida. The objective is twofold:

1. Perform a field demonstration with a pilot-scale unit at the NCBC location using the Advanced Electric Reactor (AER) process owned by the J. M. Huber Corporation of Borger, Texas. The AER is a high-temperature fluid wall reactor.
2. Provide technical evaluation and cost estimates for full-scale cleanup/site restoration using the AER technology, which would provide information to compare this technology with others.

A specific goal of this technology testing was to reduce the total isomers of tetra, penta, and hexachlorodibenzo-p-dioxin and respective isomers of polychlorodibenzofuran to less than 1 part per billion (ppb). The overall soil treatment goal of the demonstration was to reduce the level of contaminants to criteria acceptable to Headquarters, U.S. Environmental Protection Agency (EPA) to facilitate the delisting of the soil under the auspices of the Resource Conservation and Recovery Act (RCRA) of 1976, as amended by the Hazardous and Solids Waste Amendments (HSWA) of 1984.

The AER field demonstration was one of two technologies selected for the Air Force Small-Scale Demonstration Program. Those technologies are being evaluated for decontamination treatment of former Department of Defense (DOD) HO sites. The purpose of the research demonstrations is to provide actual field data on the feasibility of the technology so that

scaleup and cost-effectiveness can be determined for future restoration efforts. The other small-scale technology undergoing research is a thermal desorption process being performed by the IT Corporation (ITC) at NCBC and Johnston Island (Pacific Ocean). Results of these tests appear in separate reports.

## B. BACKGROUND

HO, primarily composed of two compounds, 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) and various esters of these two compounds, was sprayed as a defoliant in Vietnam during the 1960s and at Eglin Air Force Base, Florida, between 1962 and 1970 (References 1,2). Early in 1970, it was reported that the herbicide 2,4,5-T was a teratogen in mice and rats (Reference 3). More specifically, studies identified an unwanted by-product 2,3,7,8-tetra-chlorodibenzo-p-dioxin (TCDD), which is contained in 2,4,5-T, as the reason for the teratogenic effects (Reference 4). DOD discontinued the use of HO in 1970 (Reference 5). At that time, 850,000 gallons of HO were in storage at NCBC (Reference 6).

During the summer of 1977, the entire HO stockpile was disposed of at sea by high-temperature incineration (Project PACER HO, Reference 6). However, spills during the storage and handling of HO left the soil at the storage site contaminated with dioxin. The Air Force Logistics Command plan and EPA permits for the disposal of HO committed the Air Force to a follow-up storage site reclamation and environmental monitoring program (Reference 6). Immediately after the at-sea incineration, the U.S. Air Force Occupation and Environmental Health Laboratory (USAF/OEHL) initiated site monitoring studies of chemical residues in nearby soil, drainage water, and drainage ditch sediment at the former NCBC storage site (References 6 and 7).

## 1. Restoration Criteria

EPA presently has no polychlorodibenzo-p-dioxin or polychlorodibenzofuran criteria for restoration of treated soils. The 2,3,7,8-TCDD isomer is considered to be the most toxic polychlorodibenzo-p-dioxin/polychlorodibenzofuran isomer to man (Reference 8). This toxicity may be 10 times as toxic as the next isomer within this group (Reference 9). The Centers for Disease Control (CDC) of the U.S. Department of Health and Human Services in Atlanta, Georgia, after studying the risk of various concentrations of 2,3,7,8-TCDD in soil, has concluded that residual soil levels at or above 1 ppb of 2,3,7,8-TCDD in residential areas cannot be considered safe and represent a level of concern (Reference 10). In certain commercial areas, higher levels in the soil may represent an acceptable risk to nonoccupationally exposed individuals; however, the CDC also concluded that, on ranges and pastures, lower levels in the soil may still be of concern since 2,3,7,8-TCDD accumulates in the tissues of grazing cattle and rooting swine (Reference 10). Criteria that will be applied for actual full-scale restoration projects will depend on regulatory requirements in effect at the time, and cost effectiveness of the technologies being considered.

## 2. Storage Site Location

NCBC is a fenced, limited-access military installation (Figure 1). It is a land area of several square miles located approximately 2 miles from the Gulf of Mexico, and is approximately 20 feet above sea level. The indigenous soil is sand to sandy loam, intermixed with some clay.

Approximately 12 acres at NCBC served as an HO storage site (Figures 2 and 3). The storage site was stabilized with Portland cement approximately 30 years ago. The stabilized soil provided a hardened storage area for heavy supplies and equipment. Over the years, additional fill materials (shell, rock, soil, asphalt, and tar) were added to the storage area, providing a cover of up to several inches over the

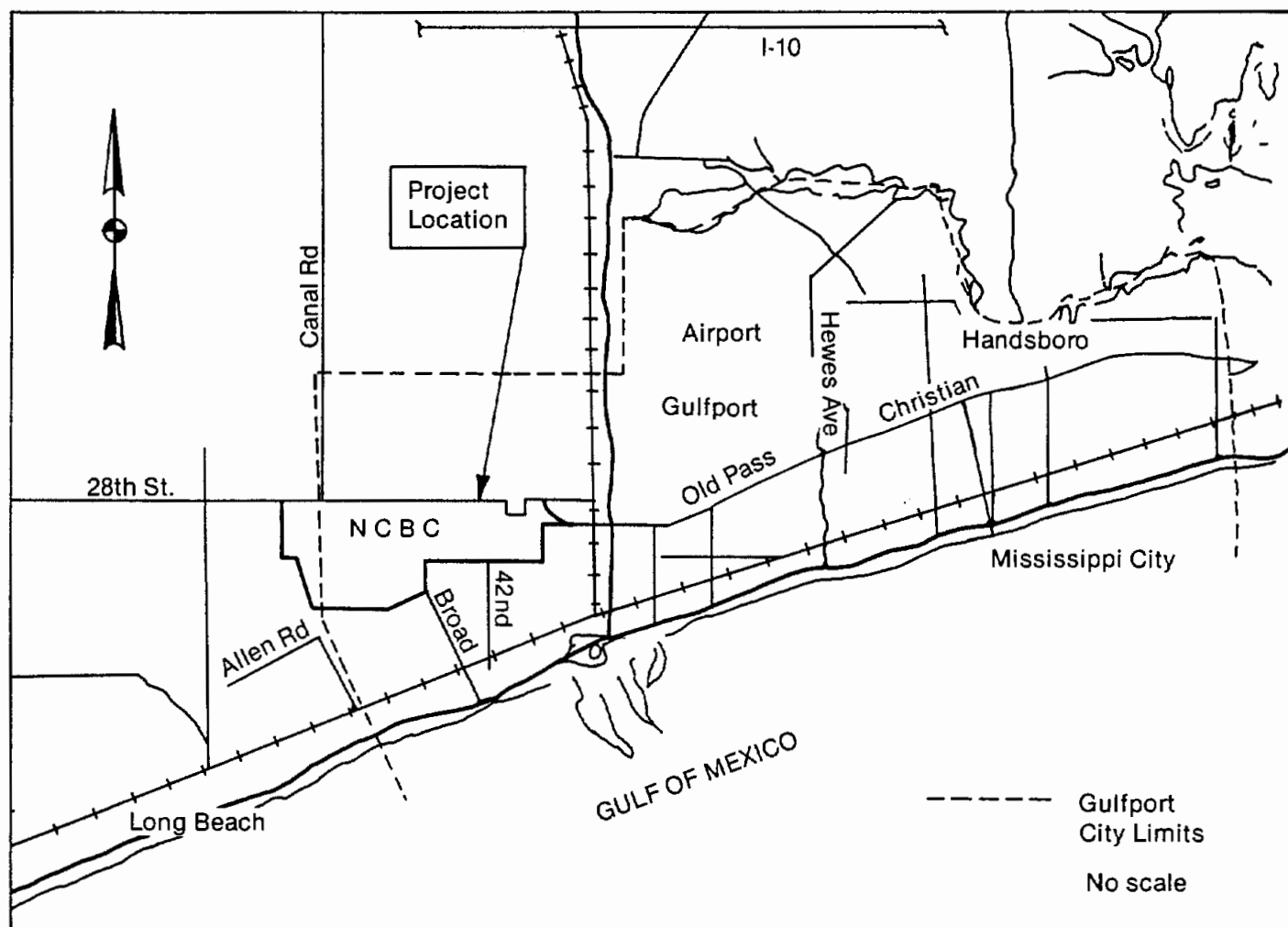


Figure 1. Naval Construction Battalion Center Vicinity Map.

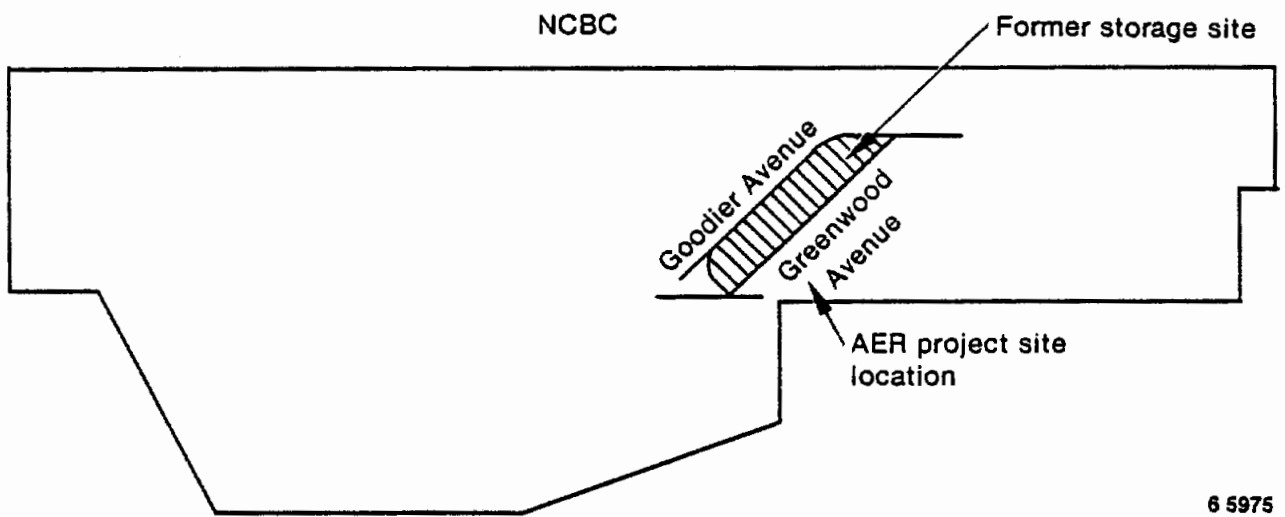


Figure 2. NCBC Perimeter and Location of Former Herbicide Orange Storage Site.

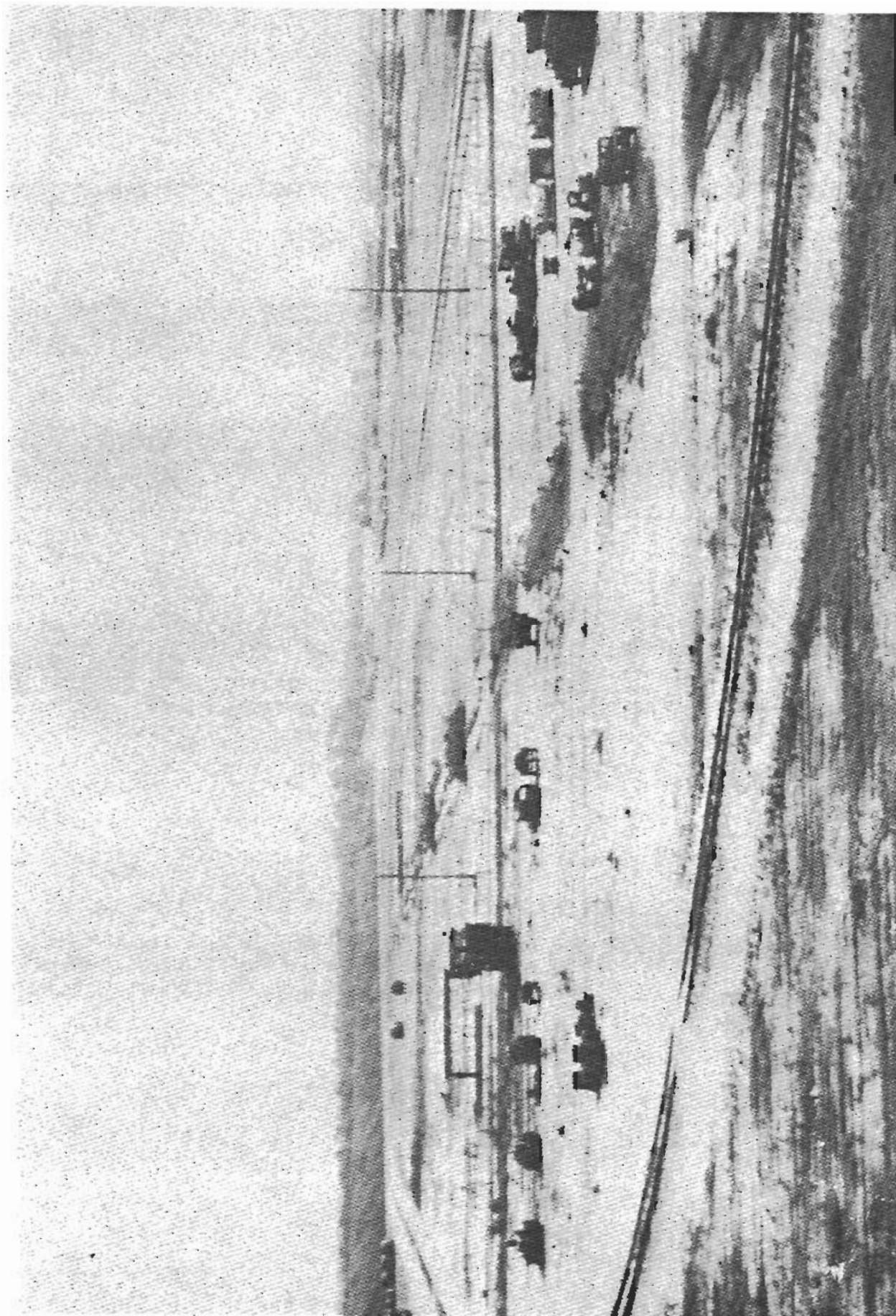


Figure 3. Overview of the NCBC Herbicide Orange Storage Site.



cement-stabilized soil. Through use, the contaminated site is now about 18 acres. During 1980, retention basins were constructed on the storage site to prevent migration of dioxin-contaminated soils offsite by surface runoff. Currently, the storage site within the fenced perimeter is a restricted area and is not used.

### 3. Previous Study

Before demonstration testing, a surface and subsurface soil sampling program was conducted to characterize 2,3,7,8-TCDD concentrations at the HO storage site. Composite sampling was performed in 20 by 20 foot grid plots. Surface concentrations of 2,3,7,8-TCDD for each grid plot are presented in Reference 11. At the soil surface, a maximum indicated hot spot concentration of 2,3,7,8-TCDD was 646 ppb. However, the maximum indicated 2,3,7,8-TCDD concentration was 998 ppb, found in the 6-inch-thick cement-stabilized subsurface soil. The 2,3,7,8-TCDD concentration in the soil beneath the cement-stabilized soil decreased to a value <1 ppb within 3 feet of depth. Sampling results also indicate that little (if any) horizontal migration of 2,3,7,8-TCDD has occurred.

### 4. EPA Authorizations

On behalf of the HQ AFESC and in accordance with the Toxic Substances Control Act (TOSCA), EG&G Idaho, Inc., transmitted a document (Reference 12) presenting technical information concerning the research, test, and evaluation activities of the USAF Environmental Restoration Program for former HO storage sites to the Dioxin Disposal Advisory Group (DDAG) of EPA for review (Appendix A, Exhibit 1). A presentation was then made to this group in Washington, D.C., on March 21, 1985. By notification in April 1985 (Appendix A, Exhibit 2), EPA granted a research waiver from notification requirements under 40 Code of Federal Regulations (CFR) Part 775 to the Air Force (HQ AFESC) to conduct the research tests. The only condition specified was that if testing should continue beyond

July 15, 1985, the effective date of the HSWA to the RCRA act for dioxin regulation, the activities would be subject to the provisions of that rule.

On April 25, 1985, HQ AFESC submitted a TOSCA notice application to EPA for disposal of TCDD-contaminated personnel protection and sampling equipment for research activities at NCBC and at Eglin AFB, Fort Walton Beach, Florida (Appendix B, Exhibit 1). Waste disposal would be by incineration at Rollins Environmental Services, Inc., Deer Park, Texas, EPA ID No. TXD0551141378. By notification on May 31, 1985 (Appendix B, Exhibit 2), EPA had no objections to the planned disposal. Planned disposal would need to occur before July 15, 1985; otherwise, the new RCRA dioxin regulation would apply.

#### 5. Public Notification

During April 22-23, 1985, a representative from HQ AFESC briefed the State of Mississippi Bureau of Pollution Control in Jackson, Mississippi. The Pollution Control Bureau determined that no permit would be required for research testing. Members of the DDAG and EPA Region IV (Atlanta, Georgia) also attended the meeting.

Formal public notice of research testing at NCBC was made in the Daily Herald, a Gulfport newspaper, on May 24, 1985 (Appendix C, Exhibit 1). This notice covered both research processes and informed the public where the TOSCA application (Reference 12) was available locally for review.

Under direction of the Tyndall AFB Public Affairs Office (TAFB/PAO), and in coordination with the Navy's NCBC/PAO, public information meetings were held locally on May 28, 1985. Attendance included a representative from the Mississippi Bureau of Pollution Control; a representative from EPA Region IV; the mayors of Biloxi, Gulfport, and Long Beach, Mississippi; and the media. After the public information meeting, articles in two Gulfport newspapers, the Sun and the Daily Herald, presented the state's position on the permit waiver (Appendix C, Exhibits 2

and 3). The HO problem and the planned research testing at NCBC were also summarized. A subsequent article in The Sun on June 6, 1985, announced the start of ITC's technology testing, with notification that the J. M. Huber AER test would be initiated later in the month (Appendix C, Exhibit 4).

#### C. SCOPE/APPROACH

The scope of this report is to document the results of a pilot-scale pyrolysis process to treat NCBC soil contaminated by polychlorodibenzo-p-dioxins and polychlorodibenzofurans and to present a cost estimate for full-scale remedial action by this process.

The approach for the initial objective was to use the Huber AER3 field unit at the NCBC site. A suitable quantity of contaminated soil (1000 pounds) was prepared to meet the necessary feedstock requirements (35-mesh sizing and 1 percent moisture), and the process was operated at near-maximum feed rate conditions to demonstrate feasibility under field conditions. Sampling and analytical laboratory activities were performed by Ecology and Environment, Inc., and California Analytical Laboratories, Inc., respectively, to provide independent verification. Analytical data were also reviewed and evaluated by EG&G Idaho.

The approach for the full-scale remedial action cost estimate was to have CH<sub>2</sub>M Hill, an organization familiar with hazardous waste contaminated sites, develop the initial estimate. Historical data and Huber AER operating experience provided the basis for the unit costs. The estimate was then reviewed and evaluated by a cost estimating group at EG&G Idaho.

## SECTION II

### TEST TECHNOLOGY

#### A. TECHNOLOGY DESCRIPTION

The Huber process uses a high-temperature, fluid wall electric reactor, whose process is based on destruction by pyrolysis rather than by oxidation (Figure 4). Therefore, typical gas effluent products produced by incineration, such as carbon monoxide, carbon dioxide, and oxides of nitrogen, are not formed in significant concentrations.

The reactor employs a new technology to rapidly heat materials to temperatures up to 4000 °F, using intense thermal radiation in the near-infrared region. A gaseous blanket of nitrogen flowing radially inward through porous core walls isolates the reactants, which can be in gaseous, liquid, or solid form. Carbon electrodes are heated. These, in turn, heat the reactor core to incandescence so that heat transfer is accomplished by thermal radiative coupling from the core to the feed materials. The only feed streams to the reactor are the solid, liquid, or gaseous wastes and the blanket gas, nitrogen. Figure 5 shows a simplified diagram of the Huber process.

For solid waste treatment, the solid feed stream is introduced at the top of the reactor by a metered screw feeder connecting an airtight feed hopper to the reactor. The solids are pretreated to a 35-mesh size (or less) and 1 percent moisture (or less) before placement in the feed hopper. Nitrogen is introduced primarily at two points in the reactor annulus, which is formed by the external containment vessel and the inner porous graphite core that creates the fluid wall. The solid feed passes by gravity flow through the reactor where pyrolysis occurs at temperatures between 3500 and 4500 °F.

After leaving the reactor, the product gas and waste solids pass through a post-reactor treatment zone (PRTZ), which has a water-cooled wall. The PRTZ provides additional residence time, but primarily cools the gas to less than 1000 °F before downstream particulate cleanup.

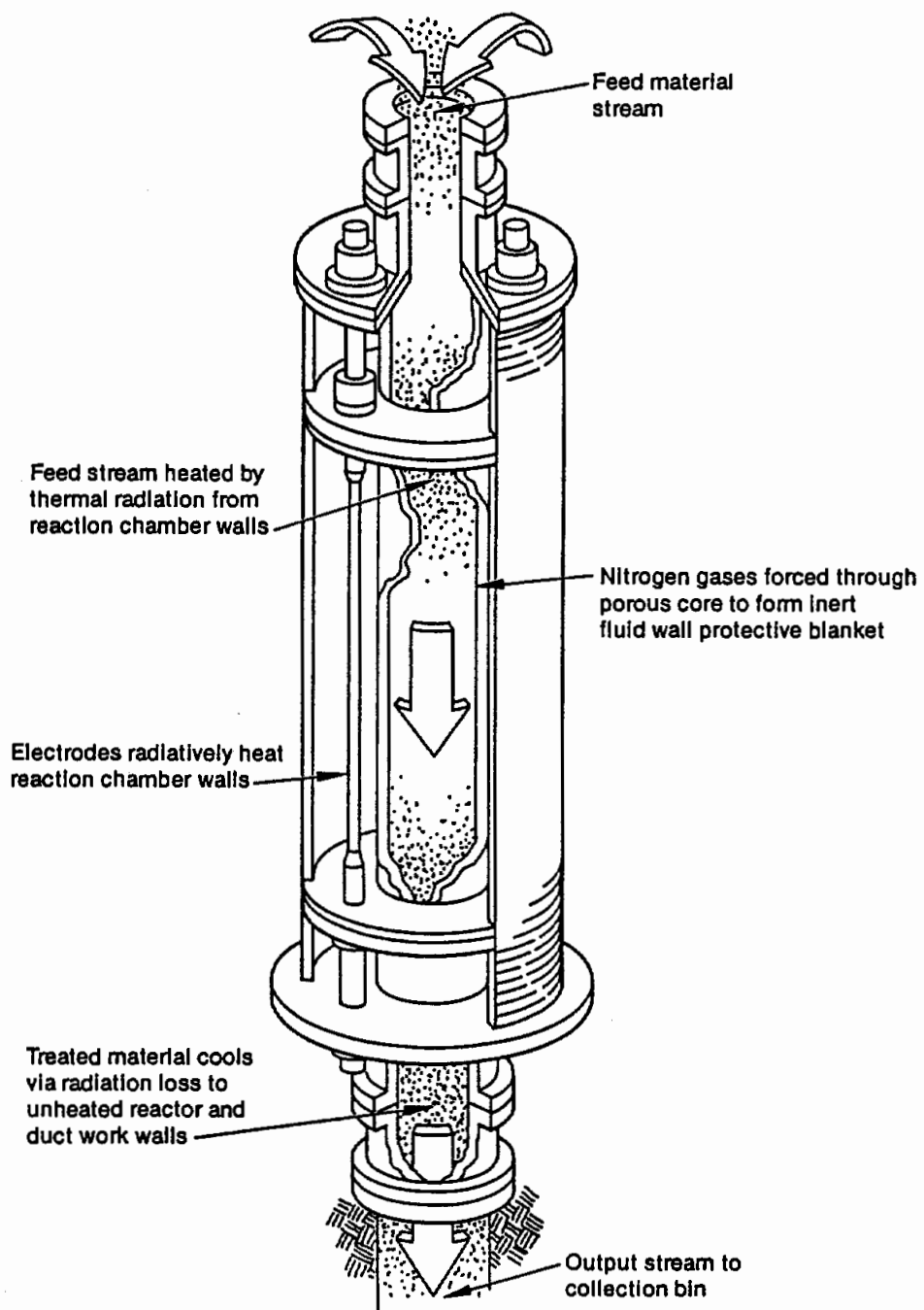


Figure 4. Advanced Electric Reactor.

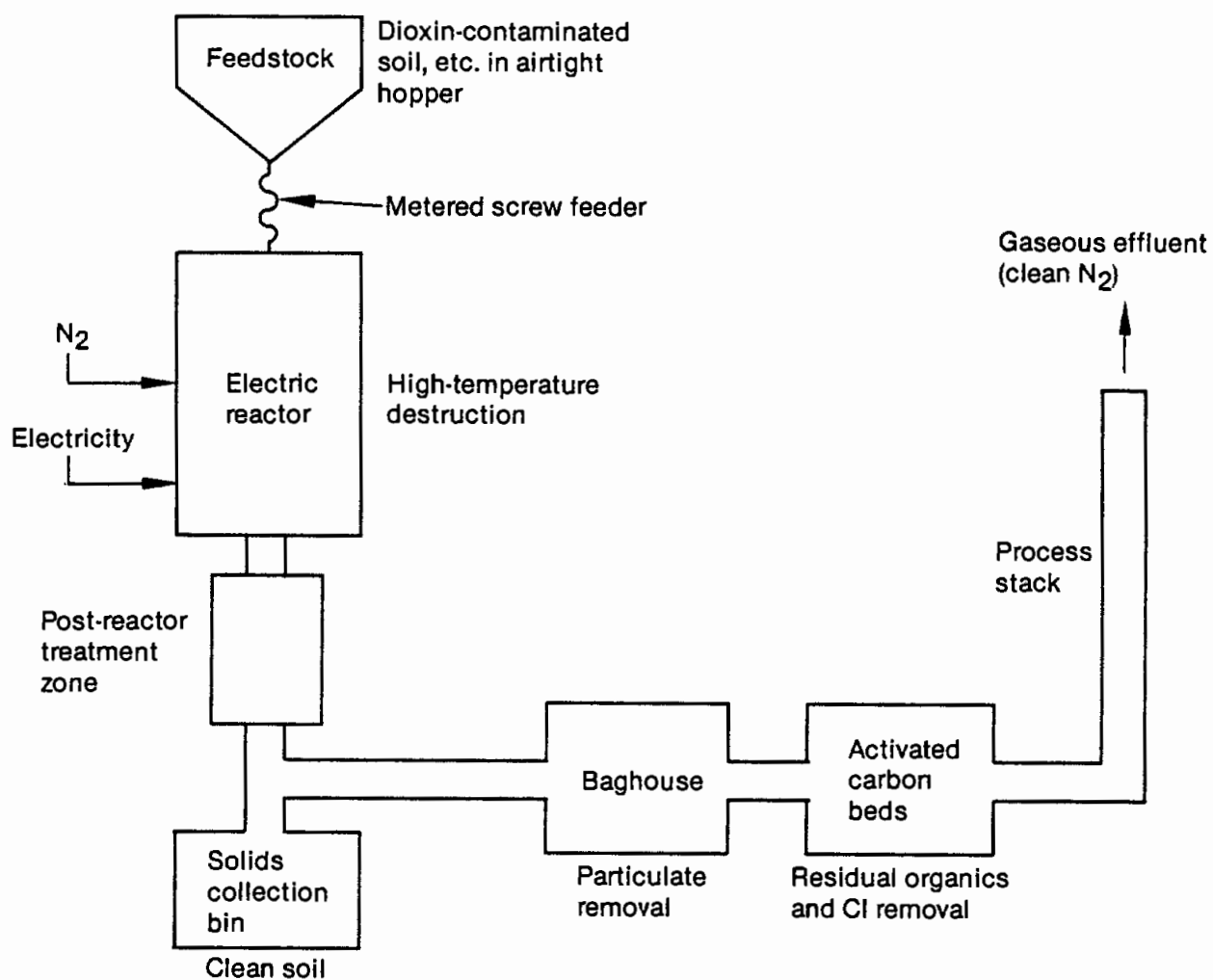


Figure 5. Simplified AER Process Diagram.

Solids exiting the PRTZ are collected in a solids bin, located below the reactor and sealed to the atmosphere. The product gas exits the PRTZ and enters a baghouse filter for fine particulate removal. Activated carbon beds installed ahead of the flue stack remove residual organics and chlorine in the gas stream. The subsequent product gas, essentially nitrogen, is then emitted to the atmosphere through the process stack.

A larger commercial-sized reactor, as presently designed (see Section VI.B), is similar in process design to the pilot-scale reactors, but has some modifications. For instance, the shell housing the reactor does not use water-cooled walls (as the pilot-scale unit), but is insulated against heat loss by using high-temperature insulation. Depending upon the application, the process design may include a wet-gas scrubber to remove chlorine gas from the flue gases. Also, an in-line heat exchanger may be used for preheating the nitrogen. Soil pretreatment requirements for the commercial-sized reactor may be less stringent than those for the pilot-scale unit. Because the differences are small, however, the cost study presented in Section VI for full-scale remedial action assumes no change in the soil pretreatment requirements.

#### B. AER EQUIPMENT DESCRIPTION

Huber maintains two fully equipped high-temperature fluid wall reactors, referred to as Advanced Electric Reactors (AER3 and AER12) at its Borger, Texas, facility. The AER3, which was used for the NCBC test and is the smaller reactor, has an inside core diameter of 3 inches with a heated length of 36 inches. It can process up to 0.6 lb/min of contaminated soil. The unit, installed in a trailer for mobility, is used for proof-of-concept experiments and onsite demonstrations. A detailed description of the AER3, as it was configured for the NCBC test, appears in Appendix D.

The AER12 reactor, which is pilot/commercial scale, has a 12-inch core diameter with a heated length of 12 feet and a capacity of up to 55 lb/min,

or 22,000 tons/year. It is used for research, i.e., scaleup design, process engineering, economic studies, and technology demonstrations.

### C. PREVIOUS AER PERFORMANCE

Before the NCBC test, four test programs were conducted to demonstrate the effectiveness of AER technology for treating soils contaminated with various types of hazardous waste. This program included demonstration tests where the AER processed soils contaminated with polychlorinated biphenyls (PCBs), carbon tetrachloride ( $\text{CCl}_4$ ), octachlorodibenzo-p-dioxin (OCDD), and dioxins including the 2,3,7,8-TCDD isomer.

The PCB trial burn, performed in September 1983, detoxified approximately 7 tons of solids. In this test, Arochlor 1260 was mixed with sand to form a solid feed waste containing approximately 3000 ppm PCBs. In May 1984, another test series used  $\text{CCl}_4$ , a very refractory (hard to thermally destroy) substance, over a wide range of test conditions. Neither test yielded results below 99.9999 percent destruction and removal efficiency (References 13 and 14).

The ability of the AER to treat dioxin-contaminated soils has also been demonstrated. In October 1984, soils contaminated with a laboratory-prepared (spiked) OCDD were processed by both the AER3 and the AER12 at the Huber facility. OCDD is a more thermally stable surrogate for the acutely toxic 2,3,7,8-TCDD isomer. In November 1984, the mobile AER3 reactor was taken to Times Beach, Missouri, where soil contaminated with 2,3,7,8-TCDD was treated. In both tests, the laboratory analysis showed no detectable dioxin in the treated soil and stack gas samples. Typically, the solids detection limits were 0.1 ppb for both OCDD and TCDD (References 15 and 16). The October 1984 OCDD tests were performed as a side-by-side comparison of AER3 and AER12 to show that scaleup of the AER does not reduce or otherwise hinder its performance. The excellent destruction results obtained on both units verified that scaleup actually eliminates minor difficulties associated with the smaller unit. Rates of



soil feeding to the AER3 and AER12 during these tests were 0.24 and 20 lb/min, respectively.

The AER12 is permitted by EPA Region VI under the auspices of TOSCA to treat PCB-contaminated soils commercially (Reference 17). In October 1985, the Texas Water Commission granted an RCRA Part B permit (HW-50082-01) for both the AER3 and the AER12 to process every listed nonnuclear RCRA waste (including dioxins).

### SECTION III

#### PILOT-SCALE FIELD TEST METHODS AND APPROACH

##### A. TEST PLAN

Huber prepared and submitted a detailed test plan to EG&G Idaho/AFESC for review before the demonstration testing (see Appendix D). The test plan called for a single test to be performed at NCBC, using the AER3 to treat about 1000 pounds of soil contaminated with approximately 200 to 300 ppb 2,3,7,8-TCDD and other polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran isomers. Feedstock soil for the AER3 would be prepared by ITC, under contract to Huber, from the same basic stock used in its technology demonstration testing. Details of the soil preparation are presented in Section IV.B. Table 1 summarizes the proposed AER3 test conditions.

All test samples would be obtained onsite by Ecology and Environment, Inc., of Buffalo, New York, and sent to California Analytical Laboratories (CAL), Inc., of West Sacramento, California, for analysis. This work was performed under contract to EG&G Idaho and served as third-party verification of test results. Later, Battelle Columbus Laboratories, Inc., of Columbus, Ohio, was included to perform limited third-party analytical services for data comparison. CAL is a certified participant in the U.S. EPA Contract Laboratory Program (CLP). Although not a participant in CLP, Battelle has performed a variety of special analytical services for EPA, including analysis for dioxins and furans.

##### B. FIELD ORGANIZATION

The Huber project field team, under the direction of a field coordinator, was divided into two groups: a process operations team of Huber personnel and an industrial hygiene team of ITC personnel, under contract to Huber. The process operations team was responsible for operating the AER3 and recording all process operating parameters. The

TABLE 1. SUMMARY OF PLANNED TEST CONDITIONS

Parameter	Conditions
Date	June 1985
Number of tests	One (1)
Feed rate	Between 0.40 and 0.55 lb/min
Reactor core temperature	3500-4500 °F
Nitrogen flow rate	6-10 sft <sup>3</sup> /min
Test duration	Approximately 30 to 40 hr
Total quantity of soil to be tested	Approximately 1000 lb
Total quantity of dioxin to be destroyed	Approximately 0.09 grams 2,3,7,8-TCDD based on average concentration in soil of 200 ppb
Soil matrix	Fractional Amount (%)
Sand/gravel	50
Shell	30
Cement-stabilized soil	20
Asphalt	Trace
Tar	Trace

industrial hygiene team was responsible for monitoring activities of the process operations team and ensuring its safe operation.

Ecology and Environment performed onsite verification sampling. This activity was coordinated with the Huber project team field coordinator.

EG&G Idaho and AFESC project personnel provided technical monitoring in the field. During field tests, this monitoring was conducted round-the-clock and served to observe, direct (but not supervise) subcontractor personnel, and ensure procedural compliance by the

demonstration and sampling effort. The AFESC project representative was also onsite during the demonstration to provide liaison with the USAF and NCBC, as necessary.

## C. HEALTH AND SAFETY

### 1. Personnel

As part of the NCBC project, Huber developed a field safety manual specifically for the NCBC test, based on experience gained through previous dioxin and PCB demonstrations (see Appendix E). The safety manual was approved by certified industrial hygienists at both ITC and EG&G Idaho.

Previous tests have verified that during actual operation, Huber's system is completely closed (References 13-16). Therefore, stringent personnel protection, referred to as Level C1, was used only when the system was open. Level C1 protection allows no exposed skin and includes the use of a Saranex<sup>®</sup>-coated environmental suit (a detailed description of C1 personnel protection is contained in the Huber Safety Manual, Appendix E). For the Huber testing, this would include use of a full-face air-purifying respirator with National Institute of Occupational Safety and Health/Occupational Safety and Health Administration-approved pesticide or organic vapor/highly toxic particulate filter cartridges or canisters. An open system existed when preparing feed material, filling feed bins, changing the treated soil collection bin, and inspecting internals of equipment components. During actual operation when the system was closed, less stringent personnel protection (referred to as Level C2, also described in the Huber Safety Manual, Appendix E) was used. These approved guidelines greatly reduced the chance for heat stress (as ambient temperatures approached 100 °F), while providing adequate personnel protection.

### 2. Equipment

An integral part of the AER system design is safety redundancy. Described briefly below are the safety features built into AER's process

design to ensure the safety of personnel and the environment when processing hazardous waste. One safety feature addresses accidental interruption of electrical power to the AER process. If this happens, the motor-driven screw-feeder stops feeding solids; and, within 1 to 2 seconds, gravity flow purges all solids from the reactor. The large amount of thermal inertia in the reactor, in proportion to the feed rate, ensures continued waste destruction and safe clearing of feed from the process in the event of a power failure. Furthermore, if for some unknown reason, dioxin (or other contaminant) passes through the reactor without being destroyed, it would be captured in the activated carbon beds. The use of activated carbon beds in the AER process is possible because of the extremely low process-gas flow rates ( $8.8 \text{ sft}^3/\text{min}$  in the AER3). If the activated carbon becomes contaminated, it is replaced. The contaminated carbon is then properly sized for AER3 feedstock and treated in the reactor.

Normal and emergency shutdown of the AER process is relatively simple. It includes the following:

- o Turn off power to screw feeder
- o Verify visually (i.e., view through quartz sight glass) that no material is being fed to the reactor
- o Isolate the screw feeder from the reactor with a manual valve
- o Turn off power to reactor.

The nitrogen purge to the reactor remains until the reactor temperature is about  $212^\circ\text{F}$  (normally this will take about 3 to 4 hours). After the reactor is cooled to less than  $212^\circ\text{F}$ , the nitrogen flow is stopped. Warning of a power loss is provided by an alarm. The AER3 is also equipped with an automatic function to cut electrical power to the reactor in the event of electrode failure.

#### D. SAMPLING

Samples were to be collected from the soil feedstock, treated soil, baghouse filter particulates, and carbon material from each of the two activated carbon filters. These sample points are identified in the system process shown in Figure 6 by the following coding:

<u>Sample Point</u>	<u>Code</u>
Soil feedstock	01
Treated soil	02
Baghouse filter particulates	03
Primary carbon filter material	09
Secondary carbon filter material	09A

Sample collection and handling procedures were in accordance with EPA methods or acceptable protocols current at the time of the tests. Specific samples taken and methods/protocols followed are discussed in Section IV.D.

#### E. ANALYTICAL LABORATORY

The goal for the AER3 demonstration test was to show that the treated soil meets the following criteria:

- o Sum of the total isomers of tetra-, penta-, and hexachlorodibenzo-p-dioxin and the same isomers of dibenzofuran are  $\leq 1$  ppb
- o Carcinogenic organics on the modified EPA Carcinogen Assessment Group's (CAG) list are  $\leq 10$  ppm (see Appendix F)
- o All organics on the modified priority pollutant list (PPL) are  $\leq 1$  ppm (see Appendix G)
- o Organics indigenous to HO and not on the PPL or CAG lists are  $\leq 10$  ppm (see Appendix H)

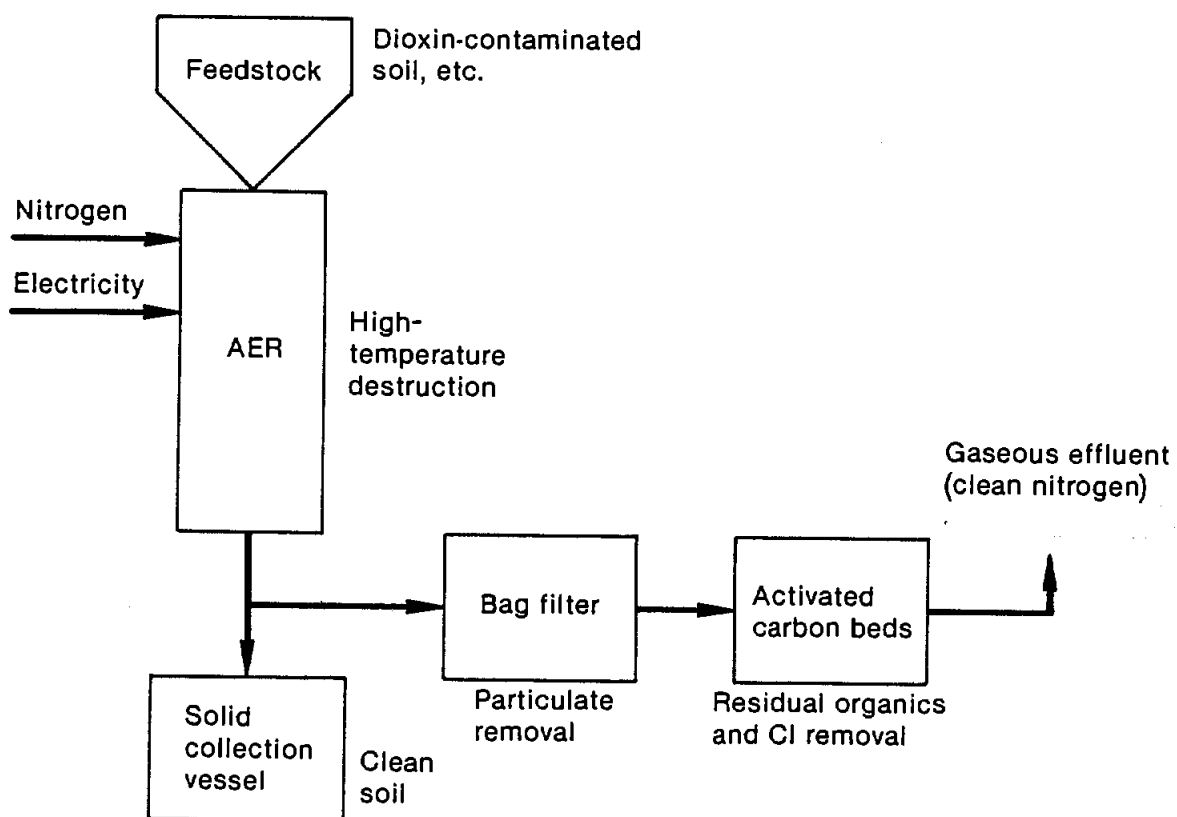


Figure 6. AER3 Process and Sample Point Schematic.

- o Inorganics (heavy metals and cyanide) listed on the modified PPL (Appendix G) are quantified. If the above tests result in concentrations greater than those limits set for any of the contaminants listed in Table 1 of 40 CFR Part 261.24, then perform the EP toxicity test per Appendix B in 40 CFR 261.

Soil sample analyses by CAL and Battelle were to provide data for assessment of meeting the above criteria. The following analysis detection limits were required by contract specification:

- o 2,3,7,8-TCDD detection limit (DL)  $\leq$  0.1 ppb
- o Total isomers of tetra-, penta-, and hexachlorodibenzo-p-dioxins DL  $\leq$  0.1 ppb
- o Total isomers of tetra-, penta-, and hexachlorodibenzofurans DL  $\leq$  0.1 ppb
- o Organics on modified PPL DL  $\leq$  1 ppm
- o Modified CAG list DL  $\leq$  10 ppb
- o Organics indigenous to HO DL  $\leq$  10 ppb
- o Inorganics on modified PPL DL  $\leq$  1 ppm
- o EP toxicity test per Appendix B in 40 CFR Part 261.

To achieve the detection limits for the first three listed, it was considered necessary to perform the analytical procedures with high-resolution gas chromatograph/mass spectrometer equipment.

In addition, CAL would perform the same tests for baghouse filter particulate material and activated carbon filter material. The detection limits mentioned above would apply for these analyses as well.



CAL's and Battelle's analysis procedures would be in accordance with EPA methods or acceptable protocols. Further, quality assurance plans would be associated with these analyses and evaluated by EG&G Idaho. The methods/protocols, results, and validation discussion are presented in Section V.A.

#### F. WASTE DISPOSAL

It was intended that contaminated non-soil-related material (personnel protection clothing/equipment, sampling equipment, baghouse filter, carbon filter material, and equipment decontamination materials) be disposed of as waste according to EPA regulations. Applications for waste disposal and EPA responses are discussed in Section I.B.4.

#### G. SOIL PRETREATMENT SHAKEDOWN TESTING

A shakedown run, sizing uncontaminated NCBC soil, was performed during May 1985 at the ITC facility in Knoxville, Tennessee. During this run, the planned equipment (Sweco<sup>®</sup> screener and Bico<sup>®</sup> pulverizer and grinder) were used to reduce approximately 200 pounds of NCBC soil for use in preliminary tests with the AER3. No problems were experienced with any of the equipment during the operation. Solar drying (Figure 7), performed before the shakedown run, indicated that supplemental drying would be required to reduce the soil moisture content below 1 percent.

#### H. AER3 SHAKEDOWN TESTING

Shakedown runs of the AER3 at the Borger facility were initiated during April 1985, with surrogate NCBC soil used to evaluate operating conditions. This effort was completed in May 1985 by an endurance run, which processed approximately 1000 pounds of soil. The AER3 operated at a temperature of 4100 °F and a feed rate of 0.57 lb/min. The soil feedback was a composite mixture consisting of 30 percent oyster shell, 25 percent cement-stabilized soil, and 45 percent sand and gravel. The mixture had been dried to less than a 1 percent moisture content and sized to

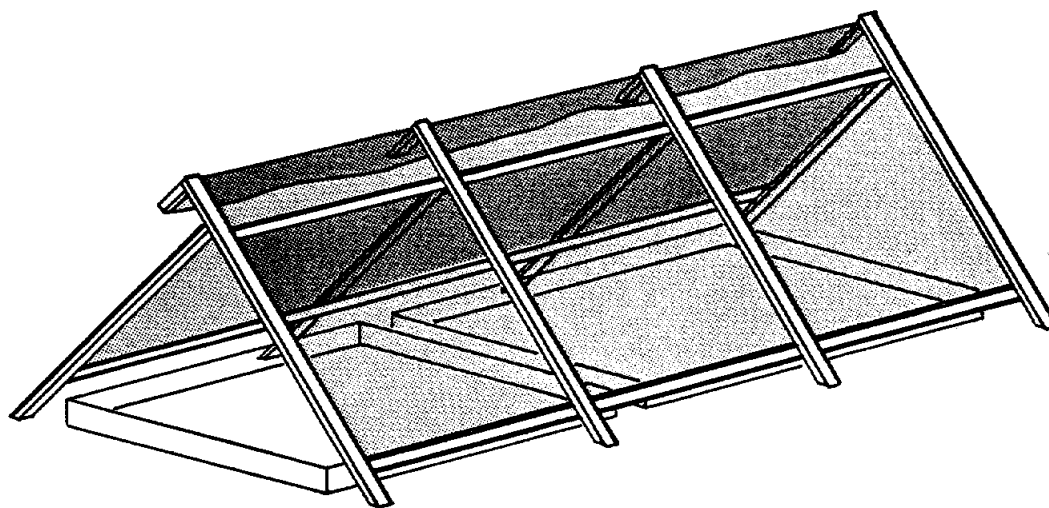


Figure 7. Solar Drying Setup for Soil Feedstock Preparation.

35 U.S. mesh.\* The feed rate was substantially greater than the 0.18 to 0.33 lb/min range used in the earlier Borger, Texas, and Times Beach, Missouri, dioxin tests (References 15 and 16) and represented a region of maximum feed rate of the AER3 by Huber. All personnel used during the endurance run were the same as those planned to be used during the NCBC testing.

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\* Moisture content and mesh size requirements based on previous Huber experience with AER3 operation.

## SECTION IV

### FIELD OPERATIONS

#### A. DESCRIPTION OF SITE SETUP AND EQUIPMENT CONFIGURATION

The AER3 trailer was located on NCBC Lot 42 near an electrical service pole, which was installed to provide 480-volt, three-phase service to the AER3 system. A cryogenic nitrogen trailer was located next to the AER3 trailer to provide nitrogen (purge gas) during operation. The soil pretreatment and equipment decontamination areas were located in Lot 63 across Greenwood Avenue (Figure 2).

The plan view of the AER3 trailer equipment layout is shown in Figure 8. The trailer is 44 feet long and 13.5 feet high, with a 10-foot-long sliding roof door above the reactor. Figure 9 shows the AER3 in the trailer. Figure 10 shows the sealed feed hopper in place above the trailer and aligned with the reactor.

#### B. SOIL FEEDSTOCK

##### 1. Selected Plot

The feedstock soil for both the Huber and the ITC demonstration tests was chosen from the area centrally located at the grid plot described as Row 24, Column 70 (see Reference 11). This area was chosen because of the known high concentration (280 ppb) of 2,3,7,8-TCDD. The material was excavated by use of a shovel and loaded into seven drums. A sample was collected from each of the five drums to be used as feedstock by ITC for its process testing. The average 2,3,7,8-TCDD concentration of the samples was 250 ppb, with a range of 232 to 272 ppb. These results were used as a general indicator of the 2,3,7,8-TCDD soil contamination for the Huber soil feedstock before pretreatment.

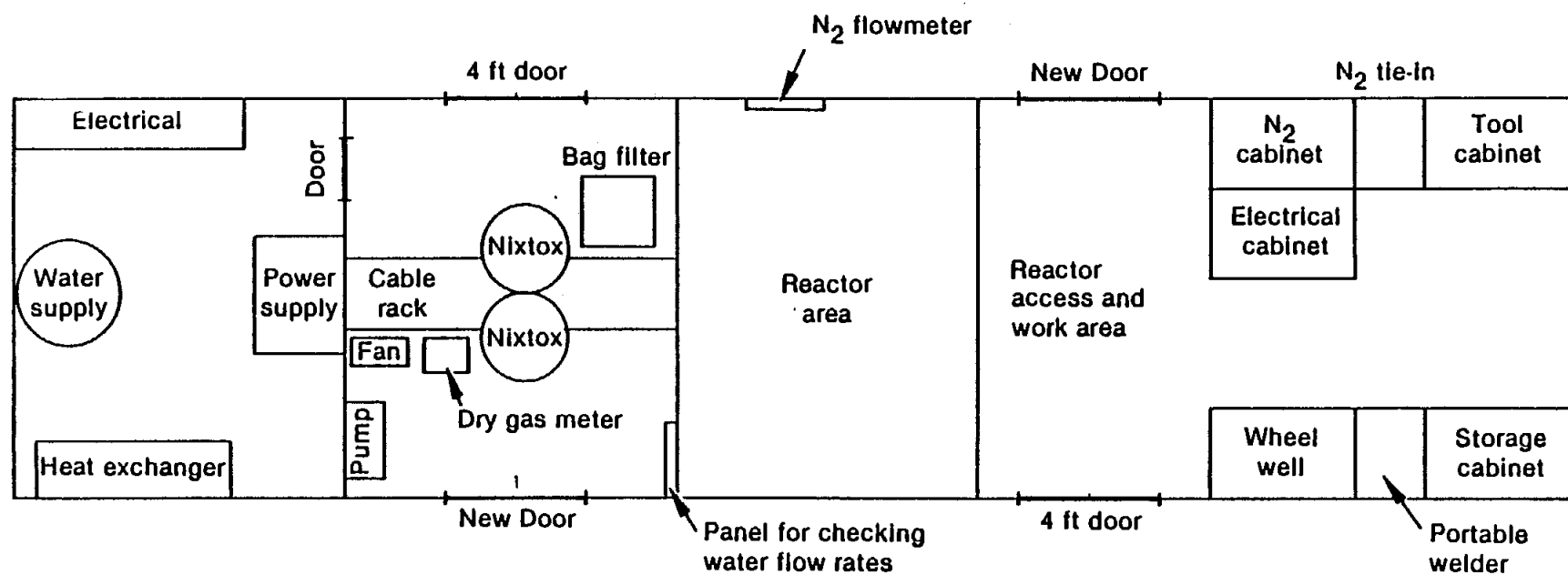


Figure 8. Plan View of AER3 Trailer Equipment Layout.

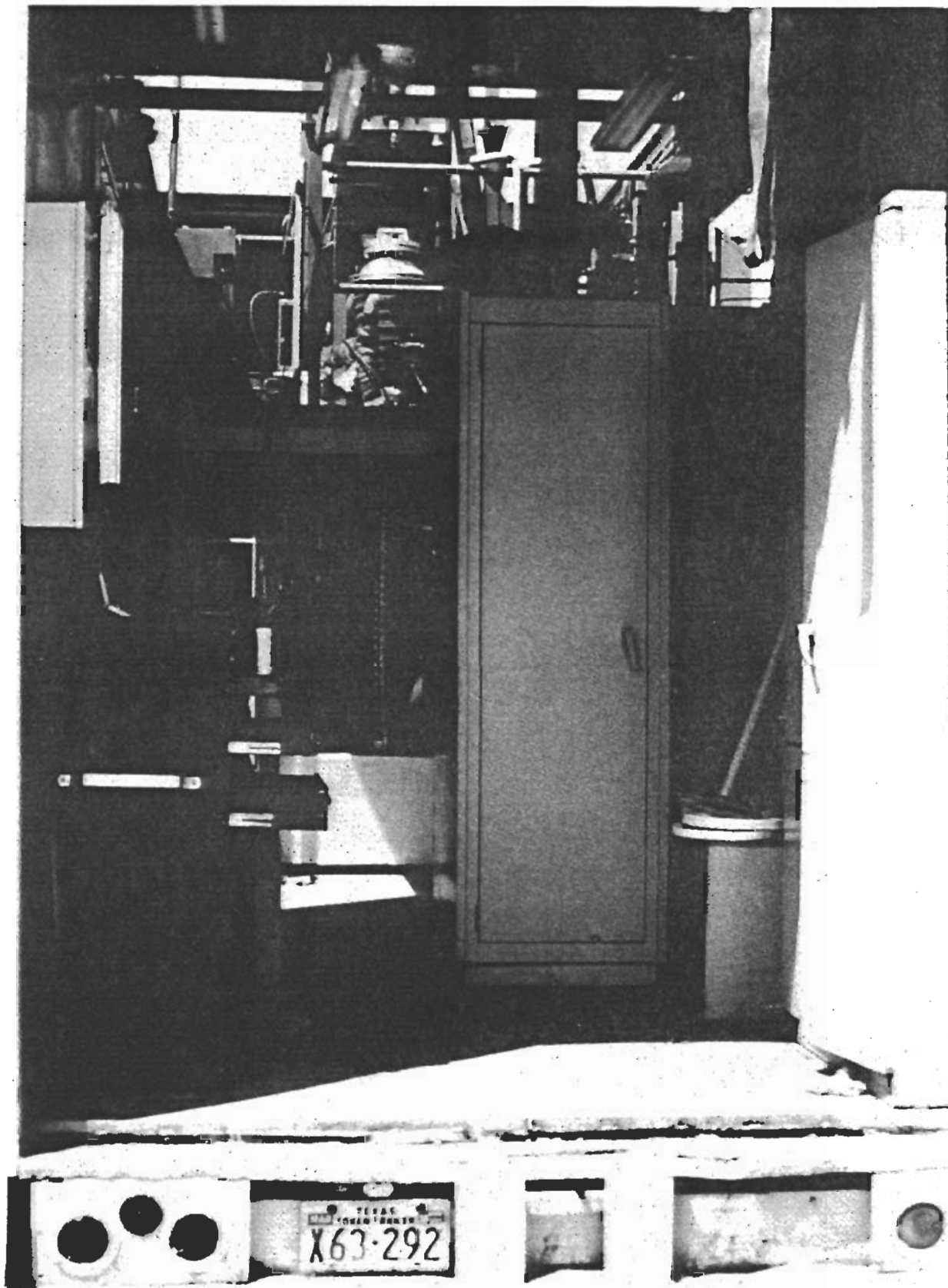


Figure 9. View of AER3 From Rear of Trailer.

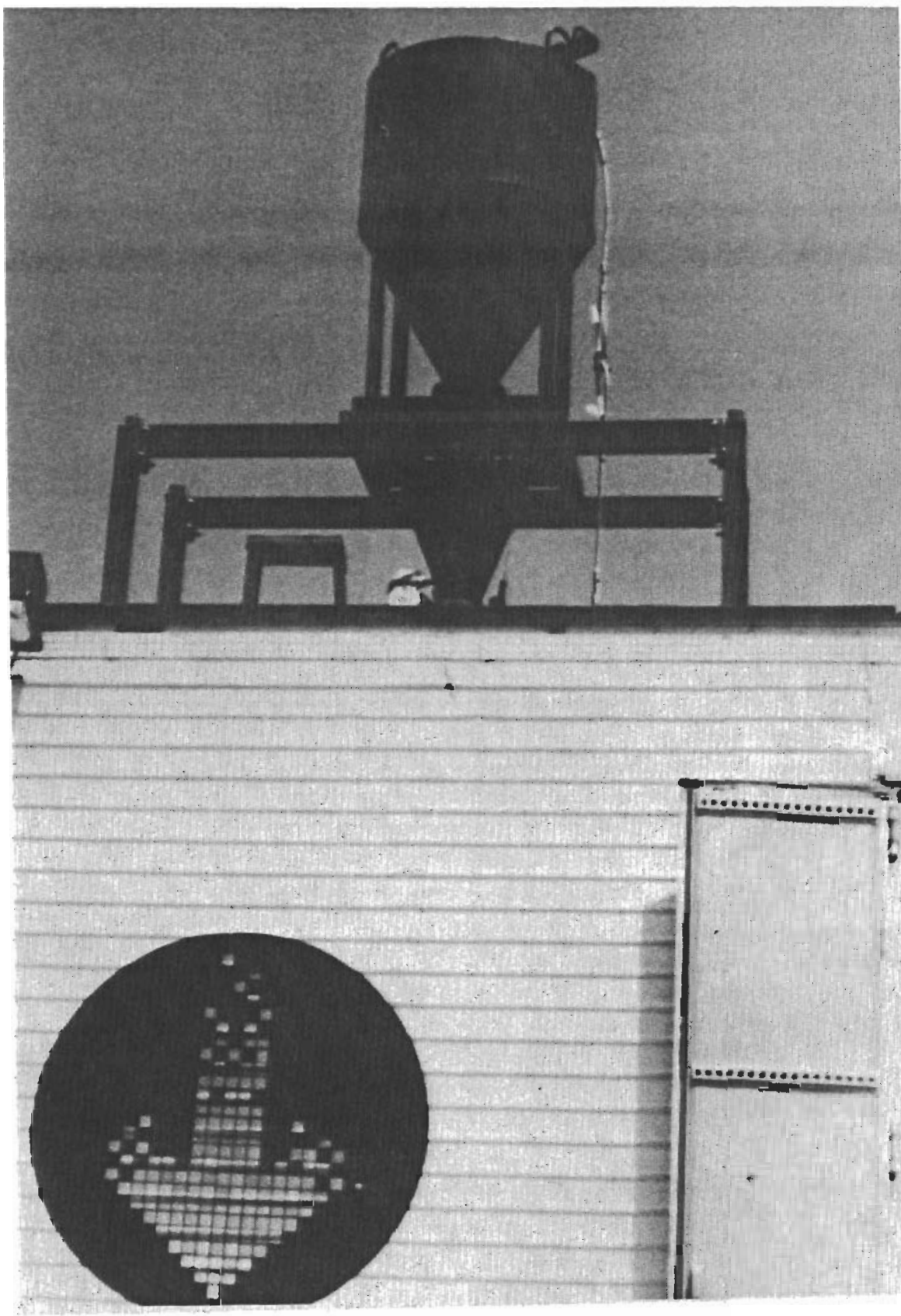


Figure 10. Sealed Feed Hopper in Place Above Reactor.

## 2. Pretreatment for AER3 Use

ITC, the subcontractor for soil pretreatment services, was responsible for the preparation of 1000 pounds of dioxin-contaminated NCBC soil, which was free flowing and dry. The plan for soil pretreatment included drying soil (using a solar dryer, Figure 7) from the remaining two of the seven soil feedstock drums. This procedure was anticipated to reduce the soil moisture content to about 5 percent by field measurement. To reduce soil moisture to the desired 1 percent, a supplemental drying system was used. The soil was heated in sealed 55-gallon drums (using electric drum heaters), and the atmosphere in the drums was purged with dry nitrogen. Then, off-gases were passed through activated carbon to prevent escape of dioxin to the atmosphere.

The soil was then coarsely crushed, using a small Bico<sup>®</sup> jaw crusher, and screened through a Sweco<sup>®</sup> 18-inch screener. The screener separated the soil into three different particle ranges:

- o Oversized soil particles larger than 35 U.S. mesh
- o Product soil particles between 35 and 120 U.S. mesh
- o Fines soil particles smaller than 120 U.S. mesh.

Oversized particles were then to be resized using a small Bico<sup>®</sup> pulverizer. Because of mechanical problems with the equipment, however, the pulverizer could not be used. Instead, the oversized particles were passed through the jaw crusher until the desired amount of properly sized soil was obtained. To ensure homogeneity of previously prepared soil with newly prepared soil, the soil batches were mixed in a cement mixer before being loaded in the AER3 feed bin. Approximately 1100 pounds of soil were prepared; the soil composition (e.g., cement-stabilized soil, sand/gravel, shell, asphalt, and tar) is shown in Table 1. No effort was made to optimize soil pretreatment because the primary emphasis of this demonstration was to test the capability of the AER3 to treat soil. Commercial-scale soil pretreatment is discussed in Section VI.



Between the soil drying and sizing phases, Huber collected two soil samples, which were sent to ITC's analytical laboratory in Knoxville for moisture and 2,3,7,8-TCDD analysis (total dioxins were not examined). These samples were collected as a field check to ensure that the soil moisture content was below the desired 1 percent level, and to verify soil 2,3,7,8-TCDD content. The results of the two samples were as follows:

- o Sample 1 had a 0.03 percent moisture content and 145 ppb 2,3,7,8-TCDD
- o Sample 2 had a 0.60 percent moisture content and 353 ppb 2,3,7,8-TCDD.

Two separate batches of soil were being prepared when these samples were collected, and each batch was sampled. Because the sample jars were mislabeled, individual results cannot be traced. The results show that the soil was significantly drier than the expected 1 percent moisture content.

#### C. TEST OPERATIONS

Two major activities were associated with the AER3 demonstration test at NCBC: onsite AER3 development runs, and the demonstration test. As discussed later, the soil matrix encountered at NCBC was different from that originally anticipated by Huber. The soil composition varied significantly within the test site. For this reason, two AER development runs were performed at NCBC before the actual test to identify and mitigate problems that might arise from processing the different soil matrix.

The following is a chronology of significant field events:

Huber equipment arrival at site, installation begun	June 7, 1985
AER3 system ready	June 9, 1985
Feedstock soil ready for initial runs	June 11, 1985

AER3 development test runs begun	June 12, 1985
Feedstock soil ready for demonstration test	June 19, 1985
AER3 demonstration test begun	June 21, 1985
AER3 demonstration test completed	June 24, 1985
Decontamination of AER3 equipment complete, Huber equipment removed	June 25, 1985
Dioxin-contaminated waste material shipped for disposal	June 28, 1985

Round-the-clock AER3 operations were supported by rotating three process operations teams under the direction of the Huber field coordinator. Each team consisted of a process engineer, lead operator, and process data operator. The industrial hygiene team activities were split between two industrial health engineers to provide full-time coverage.

Material sampling/analysis and environmental monitoring by ITC personnel are presented here as direct support of the AER3 field operation. Sampling performed by Ecology and Environment for third-party verification is reported separately in Section IV.D.

#### 1. Development Runs

To obtain the best conditions for processing the NCBC soil, the following parameters were varied during the development runs:

- o Reactor pressure
- o Reactor soil feed rate
- o Reactor temperature

- o Nitrogen flow rate
- o Nitrogen preheat temperature.

A total of 142 pounds of soil were processed: 33 pounds during the first run on June 12 and 109 pounds during the second run on June 13. The range of process parameters examined is summarized in Table 2; also listed are the process conditions Huber evaluated as best for treating the NCBC soil matrix (e.g., free flow maintained, temperature above 3500 °F). The key difference from the originally planned parameters was a lower operating temperature (3600 to 3700 °F compared to 4000 °F). A lower temperature was required to preclude soil melting, which would condense at the exit of the reactor. For further discussion of this problem, see Section IV.B.

Immediately following the tests, samples of the treated soil and filter particulates were obtained. These samples were sent to ITC's analytical laboratory in Knoxville, Tennessee, for 2,3,7,8-TCDD specific field analysis to field-test the process. Because of the amount of carbonaceous material in both samples (a result of the pyrolysis of organic material in the soil), the CLP jar extraction procedure was not sufficient for 2,3,7,8-TCDD detection. In fact, zero percent recovery efficiencies were obtained, using this method on these samples. For this reason, ITC pretreated each sample with hydrochloric acid (HCl) and used Soxhlet extraction. This modified method resulted in acceptable recovery efficiencies of 90 and 93 percent, respectively (Appendix I). The unvalidated result of the ITC analysis was that the treated soil had no detectable 2,3,7,8-TCDD at a detection limit of 0.045 ppb (Appendix I). The baghouse filter material was shown to contain 0.75 ppb 2,3,7,8-TCDD.

## 2. NCBC Demonstration Test

The AER3 NCBC test, which began on June 21, was conducted over approximately 58 hours. The average operating parameters for the run are summarized in Table 3. When soil was being fed to the reactor, the temperature was never allowed to drop below 3600 °F. For approximately

TABLE 2. AER3 OPERATING PARAMETERS DURING DEVELOPMENT RUNS

Variable	Range Examined <sup>a</sup>	Best Operating Condition <sup>a</sup>
Reactor temperature (°F)	3600-4150	3600-3700
Feed rate (lb/min)	0.4-0.6	0.6
Nitrogen preheat (°F)	70-1000	70-250
Reactor pressure inches of water	0.4-1.5	0.5-0.6
Nitrogen flow rate (sft <sup>3</sup> /min)	9-13	13

a. Data based on operator-observed readings.

b. Observed operation which maintained free flow of the soil through the reactor and at a sufficiently high temperature (3500 °F) to detoxify the soil.

TABLE 3. AVERAGED AER3 PROCESS OPERATING PARAMETERS FOR NCBC TEST

Parameter	Value <sup>a</sup>
Duration (min)	1756
Total soil treated (lb)	962
Feed rate (lb/min)	0.55
Reactor core temperature (°F)	3650
Nitrogen flow rate (sft <sup>3</sup> /min)	9-10
Flue gas flow rate (sft <sup>3</sup> /min)	13.3
Power requirement (kW)	37-40

a. Data based on operator log data sheets of observed readings. Soil weight obtained by scale.

1.5 hours near the beginning of the run, the temperature was increased to 4500 °F. However, because of soil melting, which caused plugging, the temperature had to be lowered. Most of the run was performed at a reactor core temperature between 3600 and 3700 °F. During the run, nitrogen flow was maintained between 9 and 10 sft<sup>3</sup>/min. Power consumption ranged from 1.1 to 1.2 kWh/lb of soil.

During the first 30 minutes of the test, the soil feed rate was gradually increased from 0.40 to 0.60 lb/min, where it was held during steady-state operation. The same procedure was used for adding feed to the reactor during both startup and steady-state operations. For about 2.5 hours (from 00:26 to 02:57 on June 22, 1985), the feed rate was maintained at 0.71 lb/min.

Soil was fed to the reactor for 1756 minutes (about 30 hours). Based on a total feed weight of 962 pounds, this represents an average feed rate of 0.55 lb/min. The total feed weight of 962 pounds was determined by averaging the weight of the soil as it was loaded in the feed bin using a platform scale (954 pounds), and the weight was obtained from an in-line Checkmate<sup>R</sup> scale (970 pounds). Treated soil for the demonstration runs and the NCBC test weighed 942 pounds, or 85.3 percent of the original feedstock. Separate weighings were not taken because the treated soil collection bin was not disconnected until all tests were completed. Total baghouse filter particulate material weighed 11.4 pounds, or 1 percent of the original feedstock.

### 3. Gas Sampling and Analysis

During the AER3 NCBC test, Huber collected four flue gas samples to identify quantities of nitrogen, oxygen/argon, carbon monoxide, carbon dioxide, methane, and hydrogen leaving the system. Moisture content was not measured. All four samples were collected between the baghouse filter and carbon beds. Each sample was collected with a gas-tight glass bomb, with stopcocks at both ends. A small pump was used to evacuate the bomb from one end while the sample gas was pulled in from the other end. After

the sample was obtained, both stopcocks were closed, and the sample bomb was sent to the Huber laboratory for analysis.

The analytical results, shown in Table 4, indicate that nitrogen accounted for almost all stack gases. The presence of the carbon dioxide and carbon monoxide is attributed to the decomposition of oyster shell ( $\text{CaCO}_3$ ) in the feedstock and was calculated to be about 133 pounds of gas exiting the system. Analysis data sheets are shown in Appendix J.

#### 4. Industrial Hygiene Monitoring

Industrial hygiene samples were obtained by a certified ITC industrial hygienist on June 22, 1985, during the NCBC test. ITC's report is presented in Appendix K.

As shown in Table 5, two personnel samples, one area sample, and a field blank were obtained for 2,3,7,8-TCDD analysis. The personnel sampling equipment (miniram) was placed on individuals working near the reactor feed area (near the top of the reactor) and the reactor discharge area (near the solids collection vessel). The area sample was taken inside the AER3 trailer near the solids collection bin. No 2,3,7,8-TCDD was detected; detection limits were between 600 and 750 picograms per sample or 48 and 275 picograms/cubic meter. There was no official permissible exposure limit at the time of the testing for 2,3,7,8-TCDD exposure; however, ITC used  $18 \text{ pg/m}^3$  as a company-imposed limit for its personnel at the NCBC activity. This value was based on review of 2,3,7,8-TCDD risk assessments that were performed by regulatory agencies of the PCB transformer fires at Binghamton, New York, and One Market Plaza in San Francisco, California. The protection factor of 50 for full-face air purifying respirators worn by these personnel shows that the possible personal exposure in each case was less than the ITC limit value.

TABLE 4. RELATIVE GAS CONCENTRATIONS (%) OF SYSTEM EXHAUST GAS  
DURING AER3 NCBC TEST<sup>a,b</sup>

Gas	Sample Time of Day, June 23, 1985			
	1420	1454	1605	1609
Hydrogen (H <sub>2</sub> )	0.0	0.0	0.0	0.0
Oxygen (O <sub>2</sub> )	0.0	0.0	0.0	0.0
Argon (Ar)	0.041	0.037	0.034	0.045
Nitrogen (N <sub>2</sub> )	94.585	94.721	94.788	94.976
Methane (CH <sub>4</sub> )	0.0	0.0	0.0	0.0
Carbon monoxide (CO)	1.217	1.171	1.181	1.166
Carbon dioxide (CO <sub>2</sub> )	<u>4.157</u>	<u>4.071</u>	<u>3.997</u>	<u>3.813</u>
Total	100.00	100.00	100.00	100.00

a. Exhaust sample point between baghouse filter and primary activated carbon bed filter.

b. Analysis performed by J. M. Huber Corp. at its Borger, Texas, facility. Raw data sheets are given in Appendix J.

## 5. Medical Examinations

Medical examinations of Huber operating personnel were conducted before and after the AER operation at NCBC. After reviewing the laboratory reports, histories, and photographs of the involved Huber personnel and comparing them with data of the initial examination, the medical doctor concluded that there was "... no evidence of any toxic material exposure or any ill effects from this operation." This is documented in Appendix L.

TABLE 5. 2,3,7,8-TCDD RESULTS FROM INDUSTRIAL HYGIENE SAMPLES

Sample Number <sup>a</sup>	Type Sample/ Location	TCDD Per Sample (pg) <sup>b</sup>	Air Volume Sampled (m <sup>3</sup> )	Average Concentration (pb/m <sup>3</sup> ) <sup>b</sup>
J4029	Area sample--Huber trailer inside door (reactor discharge door) opposite control panel	None detected at 630 pg <sup>c</sup>	13.08	Less than 48.2
J4030	Personnel sample--operator at reactor discharge	None detected at 600 pg <sup>c</sup>	2.81	Less than 213.5
J4031	Personnel sample--AER operator at reactor feed area	None detected at 750 pg <sup>c</sup>	2.73	Less than 274.7
J4032	Field blank	None detected at 1300 pg <sup>c</sup>	--	--

a. All samples were taken on June 22, 1985 while the AER3 was operating during the NCBC test.

b. Analysis performed by IT Corporation at their Knoxville, TN facility. Raw data sheets are in Appendix J.

c. Detection limit values shown.



## 6. Decontamination

Wipe tests were performed on equipment surfaces to establish proper decontamination before the equipment was returned to Borger, Texas. Wipe sampling procedures are presented in Appendix M. All surface wipe tests of equipment returned to Borger were below the required 150 ng/m wipe.

## 7. Residual Materials

Once the system cooled after the NCBC test run, the soils collection bin (Figure 11) containing the treated soil was unhooked from the AER3 process flow train, sampled, sealed, weighed, and placed in the buffer zone in Lot 63 of the HO storage site for temporary storage. This activity preceded decontamination of the AER3 system.

After system decontamination activities, dioxin-contaminated materials were placed in fiber drums for disposal shipment (Appendix L, Exhibit 1). Upon completion of testing, the primary and secondary activated carbon filters were removed, the carbon was placed in two 55-gallon drums, and the fiberglass drums were shipped to Rollins Environmental Services in Deer Park, Texas, for disposal by incineration. Copies of the uniform hazardous waste manifests are shown in Appendix N (Exhibits 2 and 3).

## D. THIRD-PARTY SAMPLING

### 1. Methods/Protocols

For each of the listed samples, two 16-ounce wide-mouth bottles were filled with sample material and set aside for shipment to CAL for the third-party analysis verification. Two additional bottles of treated soil were collected from the AER3 NCBC test and set aside as backup samples for shipment to Battelle in Columbus, Ohio. Two bottles of sampled soil feedstock for the development runs and two bottles of sampled treated soil from the NCBC test were also shipped to Battelle. Sampling was performed with personnel in C1 protective clothing. The sampling protocol in

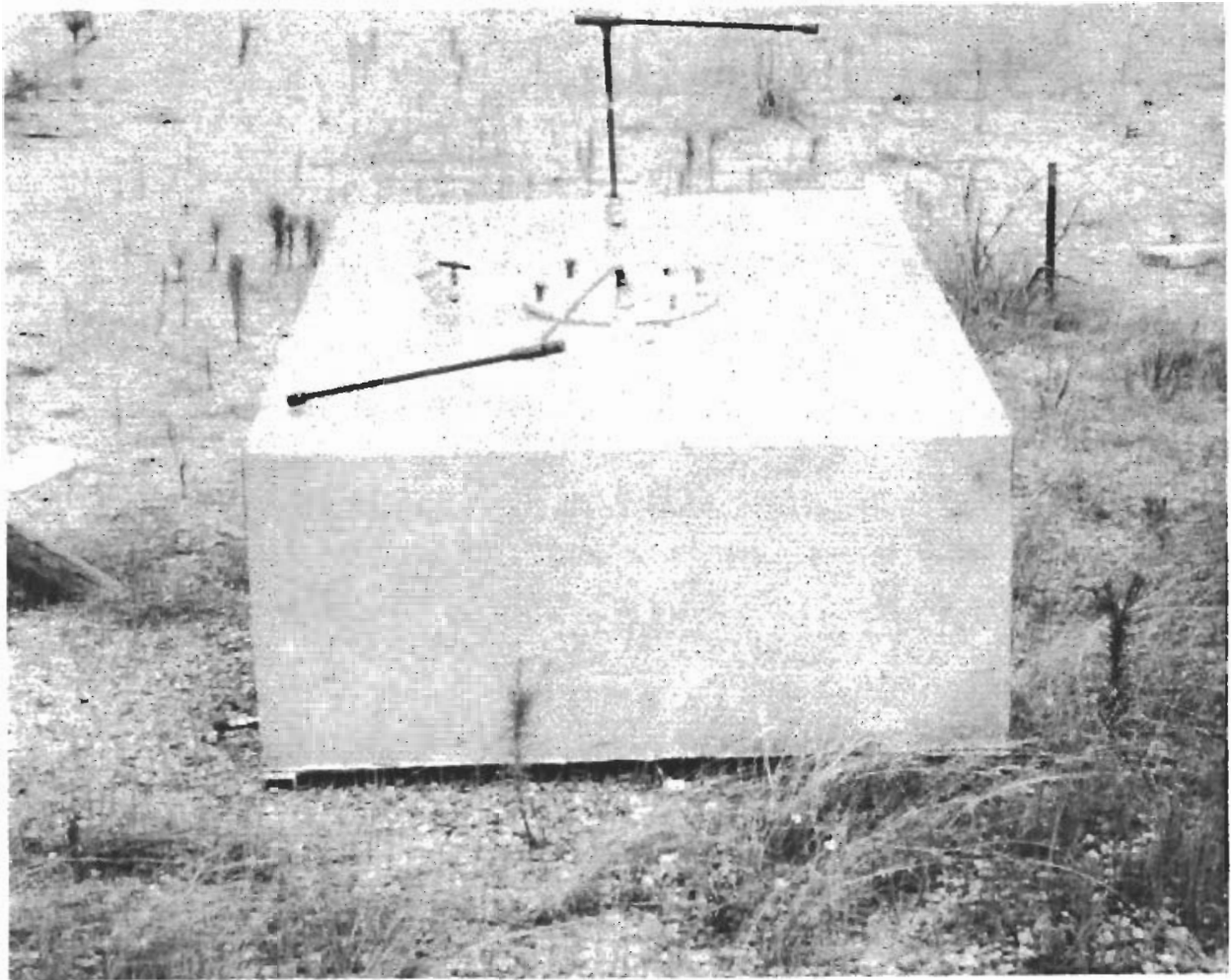


Figure 11. Solids Collection Bin Containing Treated Soil.

Appendix O provides the procedural details. The sealed bottles were packed in containers (Figure 12) for shipment to CAL and Battelle. Copies of the sample packing lists and instructions are presented in Appendix P.

## 2. Material Samples

Ecology and Environment collected the material samples listed below during the AER3 operations at NCBC. Sample identification is also listed. For sample points, see Figure 6.

<u>Sample Description</u>	<u>Identification</u>
o Soil feedstock for development runs	HU-NCBC-R1-01
o Soil feedstock for AER3 NCBC test	HU-NCBC-R2-01
o Treated soil after development runs	HU-NCBC-R1-02
o Treated soil after AER3 NCBC test	HU-NCBC-R2-02
o Baghouse filter particulate material after AER3 NCBC test	HU-NCBC-R2-03
o Primary activated carbon bed filter material after development runs	HU-NCBC-R1-09
o Primary activated carbon bed filter material after AER3 NCBC test	HU-NCBC-R2-09
o Secondary activated carbon bed filter material after AER3 NCBC test	HU-NCBC-R2-09A

Figure 13 shows the treated soil sample being taken from the collection bin after testing was completed. Note that the worker is wearing C1 protective clothing and a full respirator. Figure 14 shows treated soil collected for homogenizing in a pan before placement in sample jars. The AER-treated soil is spherical, retaining the shape of the pan. The color of the treated soil was gray because of the exposure to carbon in

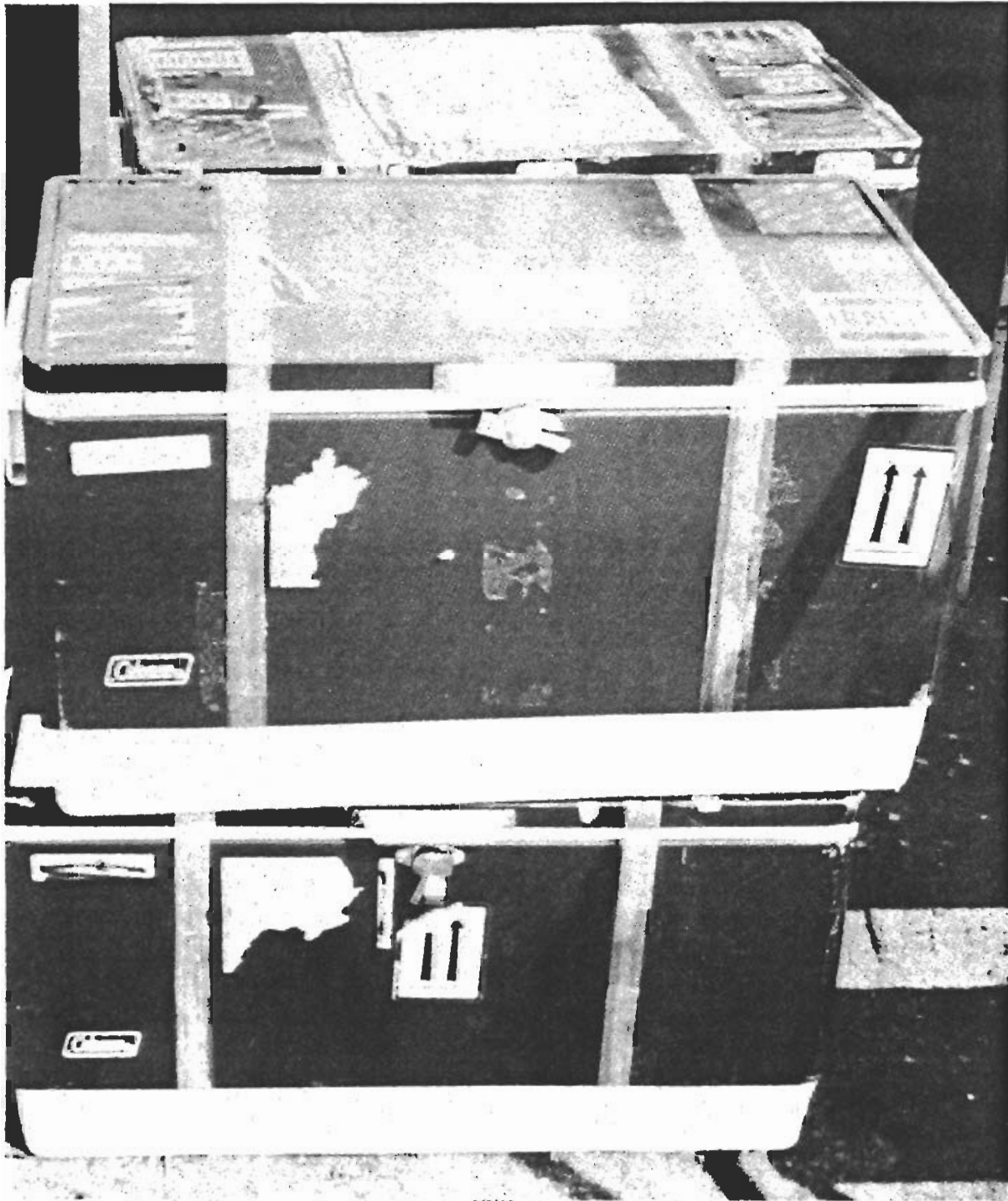


Figure 12. Sample Shipment Packaging to Analytical Laboratories.

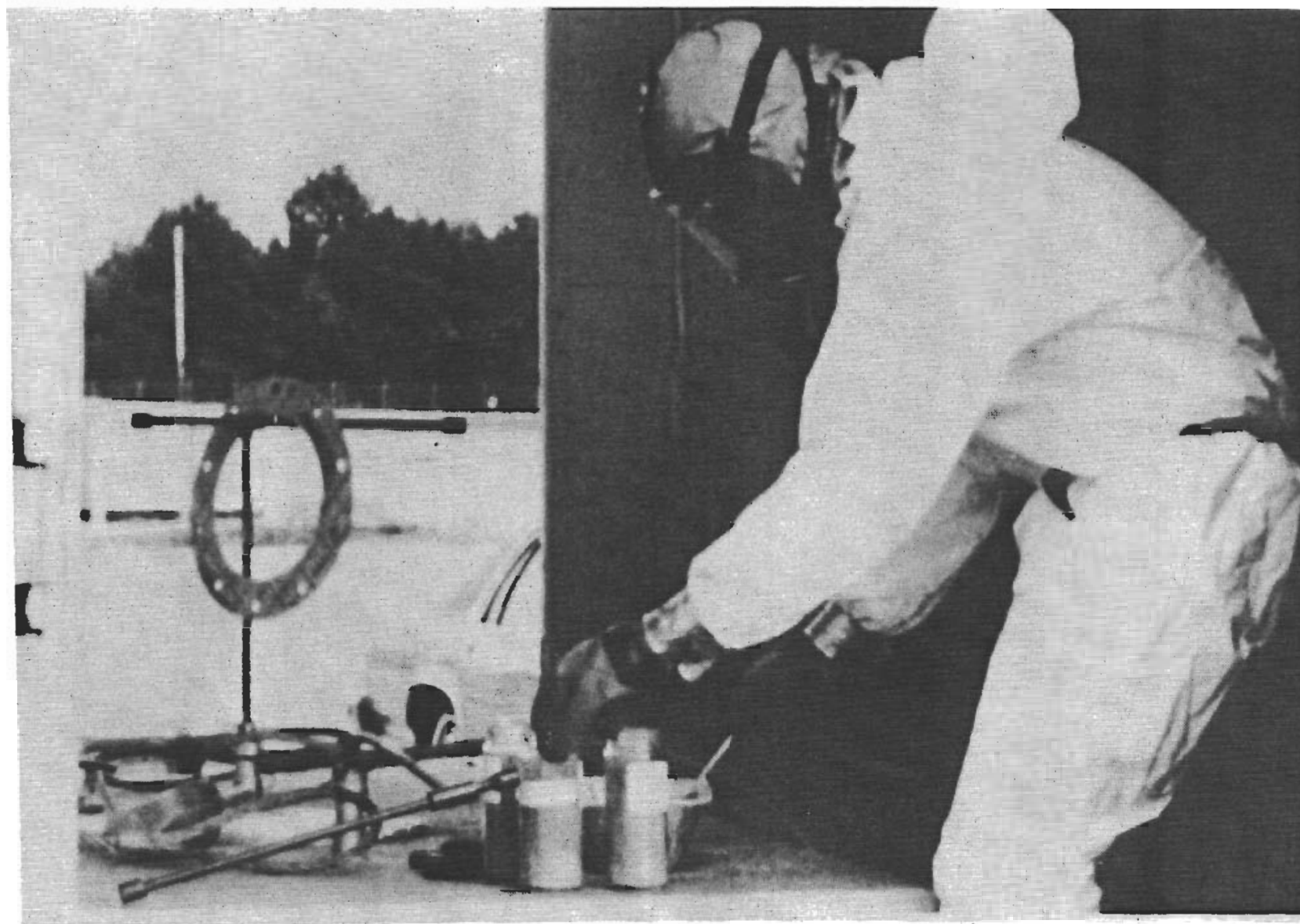


Figure 13. Treated Soil Sample Lining Taken from Solids Collection Bin.



Figure 14. Composite Treated Soil Sample Being Homogenized.

the reactor; whereas, the feedstock was whitish-colored because of the large amount of oyster shell in its composition.

### 3. Ambient Air Particulate Samples

Ecology and Environment conducted ambient air sampling at the NCBC site. This period was approximately 6 weeks, spanning soil preparation and demonstration tests for both ITC and Huber technology processes.

To determine any impact from the activities, four high-volume air particulate samplers were positioned to provide control and exposure data. The positions listed below were based on a prevailing Gulf wind in a northerly direction. The layout of the samplers is shown in Figure 15.

<u>Sampler</u>	<u>Location</u>	<u>Purpose</u>
HV-1	Upwind of site activities, about 115-130 feet	Offsite control data
HV-2	Onsite, about 115-130 feet	Onsite control data downwind of site activities
HV-3	Onsite, about 115-130 feet downwind of site activities, next to HV-2	Exposure data from onsite activities
HV-4	Downwind of site activities at the perimeter fence	Exposure data representing the general NCBC workforce and the public

Samplers HV-1, -3, and -4 were operational whenever there was field activity (e.g., excavation, pulverizing, process testing, decontamination). Sampler HV-2 was operated an equivalent amount of time, but when there was no field activity. Samplers H-1, -2, and -3 were initially set up and started operation on May 30, 1985. Sampler H-4 was set up later and started operation on June 5, 1985. Because the AER3 location later coincided with the initial position of Sampler HV-1, this unit was subsequently located about 115-130 feet farther upwind to continue control data sampling.

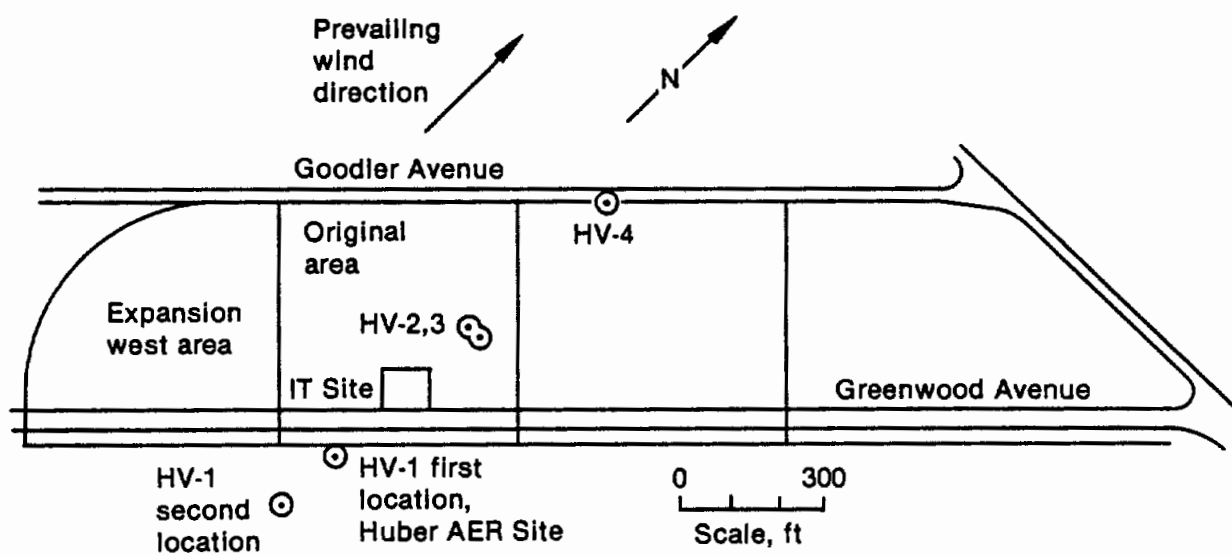


Figure 15. Layout of High-Volume Air Samplers at NCBC Site during Pilot-Scale Testing.



The filter holders were changed three times during the 6 weeks. Listed below are the samples by run, the dates installed and removed, and the estimated air volume that passed through each sampler.

<u>Run</u>	<u>Sampler</u>	<u>Sample Designation</u>	<u>Date Installed</u>	<u>Date Removed</u>	<u>Estimated Air Volume (m<sup>3</sup>)</u>
1	HV-1	EE-NCBC-R1-01	May 28	June 12	4846
	HV-2	EE-NCBC-R1-02	May 28	June 12	4636
	HV-3	EE-NCBC-R1-03	May 28	June 12	4845
	HV-4	EE-NCBC-R1-04	June 5	June 12	2877
2	HV-1	EE-NCBC-R2-01	June 12	June 22	4562
	HV-2	EE-NCBC-R2-02	June 12	June 25	4637
	HV-3	EE-NCBC-R2-03	June 12	June 22	4562
	HV-4	EE-NCBC-R2-04	June 12	June 22	4735
3	HV-1	EE-NCBC-R3-01	June 22	June 24	1761
	HV-2	EE-NCBC-R3-02	June 25	June 27	1596
	HV-3	EE-NCBC-R3-03	June 22	June 24	1761
	HV-4	EE-NCBC-R3-04	June 22	June 24	1829

Each filter was left in its holder and placed in a plastic sealed bag. These samples were packed in coolers with the material samples previously discussed for shipment to CAL.

## SECTION V

### RESULTS AND EVALUATION

#### A. THIRD-PARTY ANALYTICAL RESULTS

For each of the eight samples listed in Section II.E.2, analyses were performed by CAL for polychlorodibenzo-p-dioxins (PCDDs), polychlorodibenzofurans (PCDFs), organic and inorganic pollutants from the modified PPL, and total analysis for HO constituents 2,4-D and 2,4,5-T. To represent the full lot of feedstock, CAL tested for creosote on a sample from one of the ITC soil feedstock drums. Also, 12 air filter samples were analyzed for 2,3,7,8-TCDD and total suspended particulates (TSP). The Battelle analysis for PCDDs/PCDFs in an NCBC test-treated soil sample is also included. This section presents (1) methods/protocols (CAL), (2) methods/protocols (Battelle), (3) data review, and (4) results.

##### 1. Methods/Protocols (CAL)

The contracted intent with the primary independent analytical laboratory (CAL) was to follow methods and protocols drawn from the EPA Contract Laboratory Program to satisfy the criteria stated in Section III.E. Based on a review of the contract proposal package, review of the submitted data package (Reference 18), a visit to the laboratory, and telephone contact, all by EG&G Idaho personnel (see the detailed evaluation in Appendix Q), the actual procedures used deviated from these guidelines so that none of the data could be validated according to the EPA/CLP practices. As discussed in Section V.A.3, the submitted data were evaluated for usefulness to support the objectives of this technology test.

The following discussion summarizes the procedures followed for each analytical category. The associated quality assurance/quality control procedures associated with each analytical category are included. In some cases, problems were encountered. These are presented and explained.

Samples were submitted to CAL for analysis on June 21 and June 28, 1985.

a. PCDD and PCDF Analysis

The PCDD and PCDF analyses were to be performed according to the method specified in the EPA Invitation for Bid (IFB) for 2,3,7,8-TCDD and EPA Draft Method 8280\* (as modified by EPA's Environmental Monitoring Science Laboratory, Las Vegas) for isomer class analysis (tetra through hexa isomers). The IFB method, which is part of EPA's Contract Laboratory Program (CLP), is used for multiconcentrations of dioxin in a soil/sediment matrix by jar extraction. The analytical methods section from the IFB method document are shown in Appendix R, Exhibit 1. Acid pretreatment and Soxhlet extraction would be part of these procedures. Additional internal standards (one of each PCDD and PCDF chlorination level) would be used. Additional contract requirements were that (1) the samples would be pretreated with dilute hydrochloric acid, followed by Soxhlet extraction, and (2) high-resolution gas chromatography/mass spectroscopy (GC/MS) equipment would be used.

CAL's Quality Assurance/Quality Control (QA/QC) protocol for 2,3,7,8-TCDD was also taken from CLP. The QA/QC requirements section from the IFB method document is shown in Appendix R, Exhibit 2. The general approach for QA/QC of isomer class analyses is shown in Appendix R, Exhibit 3. Sources of standards and internal standards used (and owned) by CAL are listed in Appendix R, Exhibit 4.

Ten grams of each sample were weighed and transferred to a Soxhlet or jar extractor. All samples were spiked with 50 ng of isotopically labeled internal standard 2,3,7,8-TCDD-<sup>13</sup>C<sub>12</sub>. Samples being tested for 2,3,7,8-TCDD specific levels were additionally spiked with 10 ng of isotopically labeled surrogate compound 2,3,7,8-TCDD-<sup>37</sup>Cl<sub>4</sub>.

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\* At the time of the analysis, EPA had no approved method published. A draft Method 8280 for 2,3,7,8-TCDD was in the public review process.

Charcoal samples from the carbon filters and the air filter samples with an "EE" prefix were initially extracted by toluene in a Soxhlet extractor. The other samples were initially extracted by the IFB jar extraction method. Samples found to have very high dioxin and furan values were generally reextracted, but with a much smaller sample size. Those samples that yielded unacceptable internal standard recoveries were reextracted by the jar method and/or the Soxhlet method.

For the isomer class GC/MS analyses, calibration standards at a single concentration were run on a daily basis to determine response factors for the various analytical parameters. The standard was a mixture of the following compounds from their own standards (see Appendix R, Exhibit 4):

2,3,7,8-TCDD	2,3,7,8-TCDF
2,3,7,8-TCDD- <sup>13</sup> C <sub>12</sub>	2,3,7,8-TCDF- <sup>13</sup> C <sub>12</sub>
2,3,7,8-TCDD- <sup>37</sup> Cl <sub>4</sub>	
1,2,3,7,8-P <sub>5</sub> CDD	1,2,3,7,8-P <sub>5</sub> CDF
1,2,3,7,8-P <sub>5</sub> CDD- <sup>13</sup> C <sub>12</sub>	1,2,3,7,8-P <sub>5</sub> CDF- <sup>13</sup> C <sub>12</sub>
	2,3,4,7,8-P <sub>5</sub> CDF- <sup>13</sup> C <sub>12</sub>
1,2,3,4,7,8-H <sub>x</sub> CDD	1,2,3,4,7,8-H <sub>x</sub> CDF
1,2,3,4,7,8-H <sub>x</sub> CDD- <sup>13</sup> C <sub>12</sub>	1,2,3,4,7,8-H <sub>x</sub> CDF- <sup>13</sup> C <sub>12</sub>

There is no documented evidence of an initial multipoint calibration that would span the expected range of PCDD and PCDF concentrations in the samples. NCBC field data indicated that the concentration range could be from 200-300 ppb for feedstock, and treated soil was expected to be near 0.1 ppb or less. The analyses were conducted using high-resolution GC/low-resolution MS. The isomer class content analyses were conducted, using a DB-5 fused silica capillary GC column 60 meters long. The procedure used was to ramp the GC column temperature from 374 °F to 581 °F at a rate of 18 °F/min.

All eight Huber samples listed in Section IV.D.2 were analyzed for total TCDD, P<sub>5</sub>CDD, HCDD, TCDF, P<sub>5</sub>CDF, and HCDF content. In addition, a method blank and two native spikes were prepared. The native spikes used material from the development test feedstock sample (HU-NCBC-R1-01) and the secondary carbon filter (HU-NCBC-R2-09A). A duplicate sample using a Huber sample was not analyzed.

On certain days when 2,3,7,8-TCDD specific analyses were performed, CAL conducted a three-concentration level calibration, using standards with concentrations at 1, 5, and 25 ppb. Standards with 100 and 200 ppb concentrations were omitted in all cases. Evidence of an initial calibration is not documented. Analyses were conducted using a high-resolution GC/low-resolution MS. The feedstock (HU-NCBC-R1-01 and -R2-01) and the baghouse filter material (HU-NCBC-R2-03) samples were analyzed for 2,3,7,8-TCDD by the isomer-specific analysis method; for the other samples, 2,3,7,8-TCDD was taken from the total isomer analysis. The air filter samples with an "EE" prefix (Section IV.D.3) were also analyzed for 2,3,7,8-TCDD specific levels.

Extraction dates were not documented. However, analysis dates written in the individual sample data sheets show that groups were analyzed on August 30, September 17 and 25, and October 16, 1985. (See Appendix S, data sheets in Exhibits 2 and 8.)

#### b. Volatile Organic Compound Analysis

The volatile organic compound analysis was to be performed according to the EPA IFB method of the CLP protocol, which was based on EPA Method 624 (Reference 19). Method 624 is the GC/MS method used for analyzing purgeable organic priority pollutants in municipal and industrial wastewater. The protocol procedures are included in Appendix B of CAL's data submittal (Reference 18).

The CLP protocol states that samples for volatile organic analysis must be protected from the light and refrigerated at 39 °F from the time of receipt until they are extracted. The extraction and analysis

are to be done within 10 days of sample receipt. The samples were stored at ambient temperature and extracted on September 16, 1985, approximately 3 months after receipt (see Appendix S, Exhibit 3 data sheets). In addition, samples for volatile organic analysis were taken about 3 weeks after the containers had been opened to take samples for semivolatile organic components.

The CLP protocol also requires a 4- or 5-point calibration curve for each instrument used in the analysis. This calibration curve is necessary to determine the linearity of response for that instrument. No evidence could be found in submitted data that any calibration curve had been prepared.

All eight Huber samples were analyzed for the volatile organic priority pollutants listed in Appendix G.

c. Semivolatile Organic Compound Analysis

The base/neutral and acid semivolatile organic component analysis was agreed to be performed according to the EPA IFB method of the CLP protocol, which was based on EPA Method 625 (Reference 19). Method 625 is the GC/MS method used for analyzing base/neutral and acid organic chemicals and pesticides listed as priority pollutants in municipal and industrial wastewater. The protocol procedures are included in Appendix B of CAL's data submittal (Reference 18).

The CLP protocol states that samples for semivolatile organic analysis must also be protected from the light and refrigerated at 39 °F from the time of receipt until extracted. Also, solid samples must be extracted within 10 days of receipt, and the extract must be analyzed within 40 days of extraction. As previously discussed, the samples were stored at ambient temperature. Extractions were performed on August 27 and September 3, 1985, at least 2 months after receipt of the samples (see Appendix S, Exhibit 3 data sheets). The analyses were performed within the required time period after extraction, except where reanalysis was required.

The CLP protocol also requires a 4- or 5-point calibration curve for semivolatile organic analysis. No evidence exists that this calibration curve was prepared for the analytical instrumentation used.

All eight Huber samples were analyzed for the base/neutral and acid organic priority pollutants listed in Appendix G, except for benzidine and dimethyl nitrosamine (N-nitrosodimethyl). No reason was given for the omissions.

d. Organochlorine Pesticides and PCBs

The sample analysis for organochlorine pesticides and PCB was to be performed according to the EPA IFB method of the CLP protocol, which was based on EPA Method 608 (Reference 19). Method 608 is the gas chromatograph method used for analyzing pesticides and PCBs in municipal and industrial wastewater.

The CLP storage conditions and extraction and analysis maximum time requirements are the same as those stated for the semivolatile organic compounds. The actual storage conditions were previously noted. Extraction and analysis occurred concurrent with the base/neutral and acid semivolatile organic component activities (see Appendix S, Exhibit 3 data sheets).

Like the other organics, a 4- or 5-point calibration curve was required. There is no evidence of a calibration curve being prepared.

All eight Huber samples were analyzed for the organochlorine pesticide and PCB priority pollutants listed in Appendix G, except for endrin aldehyde, PCB-1016, -1221, and -1232. No reason was given for the omissions.

e. Inorganic Analysis

The sample analysis procedures for metals and total cyanide on the PPL were performed according to the EPA IFB methods of the CLP

protocol. These protocols were designed to digest the wide variety of solid and liquid samples found in hazardous waste sites and, thus, to release metals from the various matrices. Table 6 lists the digestive technique and CLP method reference applicable to each element analyzed.

The CLP protocol states that samples for cyanide analysis are to be stored at 39 °F, and the maximum holding time is 14 days. For mercury, the maximum holding time is 30 days. For all other metals, the maximum holding time is 6 months. It also states that for mercury and all other metals, the pH of the sample is to be adjusted to a value of 2, with nitric acid used for preservation. In the protocol, no differentiation is made between liquid and solid samples. The samples were stored at ambient temperature and without preservations. Analyses were performed on October 18, 1985, approximately 4 months after receipt of the samples.

All eight Huber samples were analyzed for the inorganic priority pollutants listed in Appendix G. In addition, five native spike samples were prepared, with known amounts of the elements being analyzed. The native spike samples used material from the NCBC test feedstock (HU-NCBC-R2-01), the development and NCBC test-treated soils (HU-NCBC-R1-02 and HU-NCBC-R2-02), and the primary carbon filter material from both the development and the NCBC tests (HU-NCBC-R1-09 and HU-NCBC-R2-09). Duplicate sample recoveries were performed for the same samples from which native spike samples were taken.

f. Compounds Indigenous to Herbicide Orange

The 2,4-D and 2,4,5-T compounds were considered as a sufficient indication of remaining compounds indigenous to HO. Many of the others listed in Appendix H are already listed as priority pollutants and were being determined, as discussed earlier. It was agreed that the gas chromatographic procedures for chlorinated herbicides in EPA Method 8150 (Reference 20) would be used. All eight Huber samples were analyzed for the 2,4-D and 2,4,5-T compounds.



TABLE 6. INORGANIC ANALYSIS DIGESTIVE TECHNIQUES AND REFERENCE METHODS

<u>Element</u>	<u>Digestive Technique</u>	<u>Reference Method</u>
Antimony	Graphite furnace AA <sup>a</sup>	204.2 CLP-M <sup>b</sup>
Arsenic	Graphite furnace AA	206.2 CLP-M
Beryllium	Graphite furnace AA	210.2 CLP-M
Cadmium	Graphite furnace AA	213.2 CLP-M
Chromium	Graphite furnace AA	218.2 CLP-M
Copper	Graphite furnace AA	220.2 CLP-M
Lead	Graphite furnace AA	239.2 CLP-M
Mercury	Cold vapor AA	245.5 CLP-M
Nickel	Graphite furnace AA	249.2 CLP-M
Selenium	Graphite furnace AA	270.2 CLP-M
Silver	Graphite furnace AA	272.2 CLP-M
Thallium	Graphite furnace AA	279.2 CLP-M
Zinc	Graphite furnace AA	289.2 CLP-M
Total cyanide	Colorimetric	335.2 CLP-M

a. AA means atomic absorption

b. CLP-M means modified for Contract Laboratory Program

g. Creosote

CAL's procedure was to compare the raw mass chromatogram of the soil samples with the chromatogram for a commercial coal-derived creosote and the creosote chromatogram provided by SUPELCO, Inc., of Bellefonte, Pennsylvania (Appendix T). This type of creosote, because of asphalt laid at parts of the former NCBC HO storage site, is a mixture of polynuclear aromatic hydrocarbons used as a biocide/biostat in the

preservation of wood. Most of the principal components of the mixture are priority pollutants, as listed in Appendix G. Samples from Huber soil feedstock or treated soil were not analyzed for creosote because of the evaluation performed earlier with chromatograms from ITC soil feedstock samples (IT-NCBC-R1-01 and -R2-01). The Huber soil feedstock was from the same source, and the ITC data would be representative (see Section IV.B.1). The ITC feedstock results are presented in Section V.A.4.a.

## 2. Methods/Protocols (Battelle)

The Battelle analyses were performed to determine specific levels for 2,3,7,8-TCDD and 2,3,7,8-TCDF and total isomer concentrations for tetra- through octachlorodibenzo-p-dioxin and tetra- through octachlorodibenzo furans in treated soil sample HU-NCBC-R2-02, to compare results with the CAL analysis data. The Battelle analytical methodology is presented in Appendix U and is summarized as follows.

Ten grams of each sample, including the duplicate and native spike samples, were weighed and transferred to Soxhlet extractors. These samples and a method blank were spiked with 25.0 ng each of three isotopically labeled internal standards: 2,3,7,8-TCDD- $^{13}\text{C}_{12}$ , 2,3,7,8-TCDF- $^{13}\text{C}_{12}$ , and OCDD- $^{13}\text{C}_{12}$ . The samples were then Soxhlet-extracted for 18 hours, using benzene. The final extracts were analyzed and quantified for PCDD/PCDF, using combined capillary column gas chromatography/high-resolution mass spectrometry.

## 3. Data Review/Evaluation

The CAL and Battelle data packages (References 18 and 21) have been reviewed by the Chemical Sciences Group at EG&G Idaho. The original intent was to review the CAL data for validation according to EPA practice. However, the elapsed holding times between sample receipt and extraction/analysis at CAL exceeded, by wide margins, the CLP allowed time periods for the analyses to be performed. The review identified other specific problems with portions of the CAL data. Differences between

actual procedures and requirements were discussed previously (see Section V.A.1 for background on procedures followed).

At the time of review, data review protocols for PCDDs and PCDFs were not universally accepted. Because of these problems, EG&G Idaho found it inappropriate to attempt to validate the results in the strict sense used by EPA. Instead, the results were reviewed and evaluated to determine if the appropriate analytical protocols were used and applied correctly, if the various calculations were correct, and if the results were consistent and adequate.

A summary of the review/evaluation follows, and a detailed report is presented in Appendix Q.

a. Dioxins and Furans (CAL)

Two types of analyses were performed for the specified PCDDs and PCDFs: total isomer class content and 2,3,7,8-isomer specific. The review methodology was to evaluate all standard data in terms of applicable ion ratios, retention times, and signal-to-noise ratios to determine if the analytical results were correctly interpreted. The isomer-specific 2,3,7,8-TCDD data were examined and evaluated, using the same criteria applied to review of results from the NCBC sampling program (Reference 11). These criteria are given in Appendix Q, and the isomer-class analysis is discussed below.

A main concern for isomer-class analyses is the use of single concentrations of analytical standards to determine response factors used in qualification. The agreed procedure to be used (Draft Method 8280) stipulates that multilevel calibration standards be used to determine response factors. This consideration is important when a wide range of concentration values are anticipated, as was the case for the Huber samples. The contract laboratory, however, ran a single-point standard on

a daily basis to determine response factors for the various analyses, as previously discussed in Section V.A.1.

The normal accepted practice is that the experimental isotope ratios (mass 1/mass 2) should be within  $\pm 15$  percent of the theoretical value to be considered a positive indicator of the presence of a PCDD or PCDF. Upon reviewing the submitted data and documentation, it was difficult to determine if this practice was followed for the isomer class data. The supporting documentation focused primarily on isomer-specific analysis, with little devoted to specific QA/QC criteria for the isomer-class analyses.

Several Huber samples were determined to have internal standards with isotope ratios slightly outside the  $\pm 15$  percent boundary. The development test-treated soil sample (HU-NCBC-R1-02) displayed a  $1,2,3,4,7,8\text{-H}_x\text{CDF-}^{13}\text{C}_{12}$  ratio of 3.389, which is slightly outside the 15 percent range. Of serious concern for this sample is that the 404 ion (mass 2 in ratio) for the  $\text{H}_x\text{CDF-}^{13}\text{C}_{12}$  standard was not found because of interferences. This required calculating the detection limit vs the TCDD- $^{13}\text{C}_{12}$  internal standard. This sample has a total detection limit of 1.304 ppb, with fairly high detection limits for  $\text{H}_x\text{CDF}$ ,  $\text{P}_5\text{CDD}$ , and  $\text{H}_x\text{CDD}$ . The NCBC test-treated soil sample (HU-NCBC-R2-02) and the baghouse filter material sample (HU-NCBC-R2-03) also displayed internal standard ratios outside  $\pm 15$  percent. None of these ratios deviated exceptionally. As the number of analyses increases, some of the criteria may be marginal or slightly outside acceptable limits. Concern should be exhibited only in those instances where exceptionally wide deviations from the  $\pm 15$  percent criteria are determined.

When originally analyzed, the Huber development test soil feedstock sample (HU-NCBC-R1-01) contained 118 ppb of tetra dioxin, with 115 ppb identified as 2,3,7,8-TCDD. This value did not agree with data gathered from isomer-specific data at other laboratories. This sample was reanalyzed under isomer-specific conditions and measured a 2,3,7,8-TCDD value of 193 ppb. The contract laboratory then scaled the total

tetrachlorodibenzo-p-dioxin based on the 2,3,7,8-TCDD value in the following manner:

$$118/115 = 1.026$$

$$1.026 \times 193 = 198.035 \text{ ppb}$$

The contract laboratory attributed the differences in values on saturation of the mass spectrometer. No evidence of saturation, however, is apparent from the submitted data. The discrepancy in values is probably because the initial analysis was conducted in the regime of nonlinear instrument response. In other words, the response of the instrument has reached a plateau and will not change significantly, even with increasing concentration. In this type of situation, a multiconcentration calibration curve is essential. When the sample was reanalyzed using isomer-specific conditions, a smaller sample size was extracted and analyzed, thus introducing a smaller amount of material into the mass spectrometer. The same type of situation is present for the NCBC test soil feedstock sample (HU-NCBC-R2-01).

As mentioned previously, two native spikes were prepared and analyzed. Of the two, the spike using the secondary carbon filter material sample (HU-NCBC-R2-09A) was of better quality because the original sample contained no detectable amounts of dioxin and furans. Recovery of the native spikes ranged from 83 to 112 percent. All recoveries were well within the acceptable range. The spike sample using development test feedstock soil sample material (HU-NCBC-R1-01) provided good recoveries, with the exception of the TCDF and TCDD, because of the high levels of material already present in the sample.

Examination of CAL's isomer-class data was a review and not a validation. When this work was performed, a single accepted, validated method for the isomer-class determination was not available. Because of this, a uniform set of evaluation criteria has not been adopted. The review was aimed at understanding the data and analytical results, and any inconsistencies were noted. The overall conclusion is that the isomer

class data can be used to identify trends in the ability of the Huber technology to decontaminate soil of PCDD and PCDF.

The following inconsistencies with the CLP isomer-specific procedures were observed:

- (1) No initial calibration curve established.
- (2) Incomplete concentration range of standards (100 ppb and 200 ppb standards omitted; TCDD contamination in the Huber soil feedstock was within this range).
- (3) Incomplete data reporting including lack of initial calibration, lack of continuing calibration, and lack of chronological list of all analyses performed.
- (4) Nonadherence to protocol concerning performance check standards.
- (5) Nonadherence to reporting format specified.

Although all isomer-specific data for Huber testing performed by CAL can be considered semiquantitative only, the data can be used to project trends in the ability of the Huber technology to decontaminate soil of 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Two sample cases for 2,3,7,8-specific results should be discussed. For the NCBC treated soil sample (HU-NCBC-R2-02), the contract laboratory used an enhanced software package to determine that a value of 0.028 ppb of 2,3,7,8-TCDF was present in the sample. Based on review of the data, the positive indication is marginal because of signal-to-noise factors. Therefore, a value of 0.028 ppb appears to be the maximum possible concentration. For the baghouse filter material sample (HU-NCBC-R2-03), the 320/322 ratio was found to be unacceptably high (1.01), resulting in a 2,3,7,8-TCDD concentration of 0.78 ppb, which should also be considered as a maximum possible concentration. The +15 percent

limit is 0.89 for the 320/322 ratio. Based on the data, it was impossible to determine if 2,3,7,8-TCDD was actually present.

Review data for the air filter samples showed the same deficiencies for the 2,3,7,8-TCDD analysis as for the Huber samples. Based on signal-to-noise criteria reported, 2,3,7,8-TCDD should be changed to "not detectable" for samples HV-EE-NCBC-R2-04 and -R3-02, with detection limit values of less than  $0.08 \text{ pg/m}^3$  and  $0.18 \text{ pg/m}^3$ , respectively. The submitted data sheets show  $0.03 \text{ pg/m}^3$  and  $0.07 \text{ pg/m}^3$ , respectively.

b. Dioxins and Furans (Battelle)

Battelle Columbus Laboratories analyzed a single Huber sample for tetra- through hexachlorinated dioxins and furans. This sample was a backup split of NCBC test-treated soil (HU-NCBC-R2-02) that had been sent to Battelle for storage in the event that the sample shipment to CAL did not reach its destination or was damaged upon receipt. When problems at CAL were identified, Battelle was requested to perform the PCDD and PCDF analyses with this backup sample (along with sample splits for soil feedstock and treated soil from a desorption test run for the ITC testing at NCBC). The data review methodology was the same as that used to review the CAL data. The results of this analysis show findings of "not detected" for all isomer classes, with detection limits ranging from 0.01 to 0.04 ppb. Battelle's data were examined and determined to meet the QA/QC criteria described in the report (Reference 21).

c. Volatile Organic Compounds

The review methodology followed the requirements specified in EPA Method 624 (Reference 19). The CAL analytical data for all samples could not be validated and are considered not usable in evaluating the Huber technology. Details have been discussed in Section V.A.1.b and are summarized below.

- (1) The samples were improperly stored between receipt and extraction.

- (2) The time between receipt and extraction was excessively long (3 months) compared to the maximum allowed time (10 days).
- (3) The sample jars were opened several weeks ahead of extraction to obtain material for the semivolatile organic analysis.
- (4) No evidence of the proper calibration procedure being performed was found.

d. Semivolatile Organic Compounds (Basic/Neutrals, Acids)

The review methodology followed the requirements specified in EPA Method 625 (Reference 19). Major discrepancies similar to those noted above were discussed in Section V.A.1.c and are summarized below.

- (1) The samples were improperly stored between receipt and extraction.
- (2) The time between receipt and extraction was excessively long (2 months) compared to the maximum allowed time (10 days).
- (3) No evidence of the proper calibration procedure being performed was found.

The analysis contract required that semivolatile compounds be analyzed to 1 ppm. It appears that the contract laboratory made an arbitrary decision about whether a given sample was analyzed as low concentration or medium concentration. On this basis, the development test and NCBC test-treated soil samples and the baghouse filter material sample (HU-NCBC-R1-02, HU-NCBC-R2-02, and HU-NCBC-R2-03, respectively) required reanalysis. The reanalysis was performed by taking the sample extract from a previous analysis and concentrating the extract from approximately 0.5 g/1 mL to 0.5 g/0.5 mL. Although this should double the concentration



and lower the detection limit by half, the reported detection limits were lowered by a factor of 4. An increase in sample injection size was not indicated. To attain the reported detection limits, the sample injection size would have to double. One other point of concern is that the detection limit is based on the peak height versus background noise level for any given component. It is, therefore, highly improbable that each component would have the same detection limit. However, the factor of 4 improvement in detection level was reported for all components.

Based on the above, the reported data could not be validated. However, because of the lower volatility of semivolatile organic compounds, the length of storage time and storage conditions would not be as critical as for the volatile organic compounds. Therefore, the data can be used to project trends in the ability of the Huber technology to decontaminate soil of base/neutral and acid type semivolatile organic compounds.

e. Organochlorine Pesticides and PCBs

The review methodology followed the requirements specified in EPA Method 608 (Reference 19). The CAL analytical data could not be validated for the same reasons summarized for the semivolatile organic compounds just discussed (see also discussion in Section V.A.1.d). However, like the semivolatile organic compound review, the reported data can be used to evaluate the Huber technology.

f. Inorganics

The review methodology followed the requirements specified in the CLP protocols (listed in Table 6). All calculations on the final data sheets were checked as correct, and the support data indicate that the proper analytical procedures were used, except for the following:

- (1) Samples were improperly stored between receipt and stored cyanide analysis.

- (2) Time between receipt and analysis was excessively long (4 months) compared to the maximum allowed for cyanide (14 days) and mercury (30 days). For other inorganics, the allowed time of 6 months was met.
- (3) There is no evidence of the samples being properly preserved at a pH of 2.

One area is of concern. Each sample was spiked, with a known amount of each element being determined. The percent recovery of the spiked elements measures the extraction efficiency. The percent recovery of each spiked element should fall within 75 to 125 percent of the amount added to the sample.

In reviewing the data, 22 spike recovery results, representing 36.5 percent of the values reported, were outside the target window. Twenty-one of the values were low, ranging from 0 to 74 percent spike recovery. The zero percent result was for antimony in the primary carbon filter material sample (HU-NCBC-R2-09). The one high result was for lead in the NCBC test soil feedstock sample (HU-NCBC-R2-01). This spike recovery value was reported as 148 percent.

The position of the contract laboratory is that these questionable spike recovery values are normal and are completely acceptable to EPA. EG&G Idaho contacted the organization performing review of inorganic analytical results for EPA and was informed that currently no action is taken if the spike recovery values are outside the stated limits. However, EG&G Idaho feels that it is indicative of questionable analytical techniques.

Based on the above, the data for metals and cyanide cannot be validated. However, the data can be used as a general guide for evaluating the Huber technology process.

#### g. Conclusions

Numerous shortcomings and omissions in the analytical data prevent any of the CAL results from being validated in a strict interpretation. The review/evaluation of the data, however, has shown that the results can be used as indicative. Therefore, the results can be used to identify trends and evaluate the probable effectiveness of the Huber process technology. It must be noted, however, that using the results to provide strict quantitative information about the process is not justified without additional corroborative information that would be provided by further Huber process testing.

The Battelle results for the single treated soil sample satisfied the detection level requirements and were supported by adequate QA/QC that met the criteria described in its report (Reference 21). Thus, these results are the most valid indication of the actual PCDD and PCDF levels in the treated soils. General conclusions must consider the limited number of soil samples (three) analyzed by Battelle for both technologies.

#### 4. Analytical Results

The analytical results are presented below in an order that follows the AER process: soil feedstock, treated soil, baghouse filter material, carbon filter material, and ambient air filters. Where appropriate, data have been combined in tables for comparison of results. Significant CAL and Battelle data sheets are included in Appendices S and U, respectively, for reference. Detailed data sheets, graphs, procedures, and quality assurance records are included in the data packages submitted by CAL and Battelle to EG&G Idaho (References 18 and 21).

##### a. Soil Feedstock

The PCDD and PCDF results for the soil feedstock used in the AER development runs (sample HU-NCBC-R1-01) and the subsequent NCBC test (sample HU-NCBC-R2-01) are shown in Tables 7 and 8. The concentrations of 2,3,7,8-TCDD and total TCDD dominated all other PCDD/PCDF isomer

TABLE 7. POLYCHLORODIBENZO-P-DIOXIN AND POLYCHLORODIBENZOFURAN  
CONCENTRATIONS IN AER DEVELOPMENT RUN SOIL  
FEEDSTOCK AND TREATED SOIL<sup>a</sup>

PCDD/PCDF	Concentration (ppb)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
<u>Dioxins</u>		
Total TCDD	196 <sup>d</sup>	<0.057 <sup>d,e</sup>
2,3,7,8-TCDD	193 <sup>f</sup>	<0.057 <sup>e,f,g</sup>
Total P <sub>5</sub> CDD	4.6	<0.29
1,2,3,7,8-P <sub>5</sub> CDD	1.5	--
Total H <sub>x</sub> CDD	2.1	<0.24
1,2,3,4,7,8-H <sub>x</sub> CDD	<0.21 <sup>e</sup>	--
<u>Furans</u>		
Total TCDF	16.3	<0.036
2,3,7,8-TCDF	3.7	<0.036
Total P <sub>5</sub> CDF	20.7	<0.063
1,2,3,7,8-P <sub>5</sub> CDF	0.21	--
2,3,4,7,8-P <sub>5</sub> CDF	0.11	--
Total H <sub>x</sub> CDF	1.0	<0.15
1,2,3,4,7,8-H <sub>x</sub> CDF	<0.084	--

a. See Appendix S, Exhibit 2, for CAL data sheets.

b. Sample ID: HU-NCBC-R1-01; CAL Lab No. 21591-1

c. Sample ID: HU-NCBC-R1-02; CAL Lab No. 21413-2RXRX\$

d. Data taken from 2,3,7,8-TCDD specific analysis

f. Percent accuracy <sup>37</sup>Cl-TCDD = 94 percent

e. Not detected. Detection limit value shown.

g. Includes isomer 1,2,3,4-TCDD, which is a small amount compared to the 2,3,7,8-TCDD isomer contribution.

TABLE 8. POLYCHLORODIBENZO-P-DIOXIN AND POLYCHLORODIBENZOFURAN  
CONCENTRATIONS IN AER NCBC TEST SOIL FEEDSTOCK AND  
TREATED SOIL<sup>a</sup>

PCDD/PCDF	Concentration (ppb)		
	Soil Feedstock <sup>b</sup>	Treated Soil (CAL) <sup>c</sup>	Treated Soil (Battelle) <sup>d</sup>
<u>Dioxins</u>			
Total TCDD	113 <sup>e</sup>	<0.036 <sup>f</sup>	<0.04 <sup>f</sup>
2,3,7,8-TCDD	111 <sup>g</sup>	<0.036 <sup>h,i</sup>	<0.04
Total P <sub>5</sub> CDD	3.2	<0.18	<0.03
1,2,3,7,8-P <sub>5</sub> CDD	1.0	--	--
Total HCDD	1.1	<0.070	<0.02
1,2,3,4,7,8-H <sub>x</sub> CDD	<0.026 <sup>f</sup>	--	--
<u>Furans</u>			
Total TCDF	12.7	0.028	<0.01
2,3,7,8-TCDF	2.7	0.028 <sup>j</sup>	<0.01
Total P <sub>5</sub> CDF	18.8	<0.019	<0.01
1,2,3,7,8-P <sub>5</sub> CDF	<0.24	--	--
2,3,4,7,8-P <sub>5</sub> CDF	0.091	--	--
Total H <sub>x</sub> CDF	0.65	<0.020	<0.01
1,2,3,4,7,8-H <sub>x</sub> CDF	<0.10	--	--

a. See Appendix S, Exhibit 2, for CAL data sheets; see Appendix U for Battelle data table.

b. Sample ID: HU-NCBC-R2-01; CAL Lab No: 21591-1

c. Sample ID: HU-NCBC-R2-02; CAL Lab No: 21591-3RX\$

d. Sample ID: HU-NCBC-R2-02

e. Data taken from 2,3,7,8-TCDD specific analysis

f. Not detected. Detection limit value shown.

g. Percent accuracy <sup>37</sup>Cl-TCDD = 118 percent

h. Includes isomer 1,2,3,4-TCDD, which is a small amount compared to the 2,3,7,8-TCDD isomer contribution.

i. Percent accuracy <sup>37</sup>Cl-TCDD = 89 percent

j. Used enhanced software to determine value.

specifics and totals. For the development run soil feedstock, the concentrations were 193 and 196 ppb, respectively. Concentrations in the NCBC test soil feedstock were 111 and 113 ppb, respectively. The total TCDD value was scaled from the 2,3,7,8-TCDD specific analysis, as shown in Section V.A.3.a.

The analytical results for semivolatile organic compounds in the soil feedstock used for the development runs and NCBC test are presented in Tables 9 and 10. Except for the three compounds listed below, which are constituents of HO (see Appendix H), semivolatile organic compounds were not detectable at the detection limit values (DLVs) shown, which were consistently above the required DL or  $\leq 1.0$  ppm. The DLVs ranged between 1 and 20 ppm.

The analytical results indicate no organochlorine pesticides or PCB in either soil sample (Tables 11 and 12). With the exception of toxaphene which had DLVs of 10 and 6.7 ppm, respectively, the DLVs were 1.0 ppm or less, as required. Results for volatile organic compounds in these soil samples are not presented because the data have been determined to be invalid and are not usable. This determination, which is discussed in Section V.A.3.c, applies to all volatile organic compound analysis results performed by CAL.

The analysis results for inorganic priority pollutants in the development runs and NCBC test soil feedstock are presented in Tables 13 and 14. Zinc has the highest concentration in each case at 108 and 70 mg/kg (ppm), respectively. Other elements detected (in descending order of concentration) were lead, chromium, arsenic, copper, and nickel. Detection limits for the other elements are shown in the above tables.

TABLE 9. SEMIVOLATILE ORGANIC COMPOUND CONCENTRATIONS IN AER DEVELOPMENT  
RUN SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup>

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
<u>Acid Type</u>		
2,4,6-Trichlorophenol	310 <sup>d</sup>	<1.0 <sup>d,e</sup>
4-Chloro-3-methylphenol (p-Chloro-m-cresol)	<4.0 <sup>e</sup>	<1.0
2-Chlorophenol	<4.0	<1.0
2,4-Dichlorophenol	36	<1.0
2,4-Dimethylphenol	<4.0	<1.0
2-Nitrophenol	<8.0	<2.0
4-Nitrophenol	<20	<5.0
2,4-Dinitrophenol	<20	<5.0
2-Methyl-4,6-dinitrophenol (4,6-Dinitro-o-cresol)	<8.0	<2.0
Pentachlorophenol	<4.0	<1.0
Phenol	1.8 <sup>f</sup>	<1.0
<u>Base/Neutral Type</u>		
Acenaphthylene	<4.0	<1.0
1,2,4-Trichlorobenzene	<4.0	<1.0
Hexachlorobenzene	<4.0	<1.0
Hexachloroethane	<4.0	<1.0
bis (2-Chloroethyl) ether	<4.0	<1.0
2-Chloronaphthalene	<4.0	<1.0
1,2-Dichlorobenzene	<4.0	<1.0
1,3-Dichlorobenzene	<4.0	<1.0
1,4-Dichlorobenzene	<4.0	<1.0
3,3'-Dichlorobenzidine	<8.0	<2.0
2,4-Dinitrotoluene	<8.0	<2.0
2,6-Dinitrotoluene	<8.0	<2.0
Fluoranthene	<4.0	<1.0
4-Chlorophenyl phenyl ether	<4.0	<1.0
4-Bromophenyl phenyl ether	<4.0	<1.0

TABLE 9. SEMIVOLATILE ORGANIC COMPOUND CONCENTRATIONS IN AER DEVELOPMENT  
RUN SOIL FEEDSTOCK AND TREATED SOIL (CONTINUED)

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
bis (2-Chloroisopropyl) ether	<8.0	<2.0
bis (2-Chloroethoxy) methane	<8.0	<2.0
Hexachlorobutadiene	<4.0	<1.0
Hexachlorocyclopentadiene	<4.0	<1.0
Isophorone	<4.0	<1.0
Naphthalene	<4.0	<1.0
Nitrobenzene	<4.0	<1.0
Diphenyl nitrosamine (N-nitrosodiphenylamine)	<4.0	<1.0
Di-n-propyl nitrosamine (N-Nitrosodi-n-propylamine)	<4.0	<1.0
bis (2-Ethylhexyl) phthalate	<4.0	0.48 <sup>f</sup>
Benzyl butyl phthalate	<4.0	<1.0
Di-n-butyl phthalate	<4.0	<1.2
Di-n-octyl phthalate	<4.0	<1.0
Diethyl phthalate	<4.0	<1.0
Dimethyl phthalate	<4.0	<1.0
Benzo(a)anthracene	<4.0	<1.0
Benzo(a)pyrene	<8.0	<1.0
Benzo(b)fluoranthene	<8.0 <sup>g</sup>	<1.0 <sup>g</sup>
Benzo(k)fluoranthene	<8.0 <sup>g</sup>	<1.0 <sup>g</sup>
Chrysene	<8.0	<1.0
Acenaphthylene	<4.0	<1.0
Anthracene	<4.0	<1.0
Benzo(g,h,i)perylene	<8.0	<1.0
Fluorene	<4.0	<1.0



TABLE 9. SEMIVOLATILE ORGANIC COMPOUND CONCENTRATIONS IN AER DEVELOPMENT  
RUN SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup> (CONCLUDED)

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
Phenanthrene	<4.0	<1.0
Dibenzo(a,h)anthracene	<8.0	<1.0
Indeno(1,2,3-c,d)pyrene	<8.0	<1.0
Pyrene	<4.0	<1.0

a. Analysis not made for benzidine and dimethyl nitrosamine (N-nitrosodimethyl) as listed in the modified PPL (see Appendix G); See Appendix S, Exhibit 3, for CAL data sheets.

b. Sample ID: HU-NCBC-R1-01; CAL Lab No: 21591-1

c. Sample ID: HU-NCBC-R1-02; CAL Lab No: 21413-2

d. Includes 2,4,5 isomer

e. Symbol (<) means not detected. Detection level value shown.

f. Estimated value

g. Compounds co-elute--analyzed as a single compound.

TABLE 10. SEMIVOLATILE ORGANIC COMPOUND CONCENTRATIONS IN AER NCBC TEST  
SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup>

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
<u>Acid Type</u>		
2,4,6-Trichlorophenol	55 <sup>d</sup>	<1.0 <sup>d,e</sup>
4-Chloro-3-methylphenol (p-Chloro-m-cresol)	<1.0 <sup>e</sup>	<1.0
2-Chlorophenol	<1.0	<1.0
2,4-Dichlorophenol	10	<1.0
2,4-Dimethylphenol	<1.0	<1.0
2-Nitrophenol	<2.0	<2.0
4-Nitrophenol	<5.0	<5.0
2,4-Dinitrophenol	<5.0	<5.0
2-Methyl-4,6-dinitrophenol (4,6-Dinitro-o-cresol)	<2.0	<2.0
Pentachlorophenol	<1.0	<1.0
Phenol	3.4	<1.0
<u>Base/Neutral Type</u>		
Acenaphthylene	<1.0	<1.0
1,2,4-Trichlorobenzene	<1.0	<1.0
Hexachlorobenzene	<1.0	<1.0
Hexachloroethane	<1.0	<1.0
bis (2-Chloroethyl) ether	<1.0	<1.0
2-Chloronaphthalene	<1.0	<1.0
1,2-Dichlorobenzene	<1.0	<1.0
1,3-Dichlorobenzene	<1.0	<1.0
1,4-Dichlorobenzene	<1.0	<1.0
3,3'-Dichlorobenzidine	<2.0	<2.0
2,4-Dinitrotoluene	<2.0	<2.0
2,6-Dinitrotoluene	<2.0	<2.0
Fluoranthene	<1.0	<1.0
4-Chlorophenyl phenyl ether	<1.0	<1.0
4-Bromophenyl phenyl ether	<1.0	<1.0

TABLE 10. SEMIVOLATILE ORGANIC COMPOUND CONCENTRATIONS IN AER NCBC TEST  
SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup> (CONTINUED)

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
bis (2-Chloroisopropyl) ether	<2.0	<2.0
bis (2-Chloroethoxy) methane	<2.0	<2.0
Hexachlorobutadiene	<1.0	<1.0
Hexachlorocyclopentadiene	<1.0	<1.0
Isophorone	<1.0	<1.0
Naphthalene	<1.0	<1.0
Nitrobenzene	<1.0	<1.0
Diphenyl nitrosamine (N-nitrosodiphenylamine)	<1.0	0.82 <sup>f</sup>
Di-n-propyl nitrosamine (N-Nitrosodi-n-propylamine)	<1.0	<1.0
bis (2-Ethylhexyl) phthalate	<1.0	<1.0
Benzyl butyl phthalate	<1.0	<1.0
Di-n-butyl phthalate	<1.0	0.74 <sup>f</sup>
Di-n-octyl phthalate	<1.0	<1.0
Diethyl phthalate	<1.0	<1.0
Dimethyl phthalate	<1.0	<1.0
Benzo(a)anthracene	<1.0	<1.0
Benzo(a)pyrene	<2.0	<1.0
Benzo(b)fluoranthene	<2.0 <sup>g</sup>	<1.0
Benzo(k)fluoranthene	<2.0 <sup>g</sup>	<1.0
Chrysene	<2.0	<1.0
Acenaphthylene	<1.0	<1.0
Anthracene	<1.0	<1.0
Benzo(g,h,i)perylene	<2.0	<1.0
Fluorene	<1.0	<1.0

TABLE 10. SEMIVOLATILE ORGANIC COMPOUND CONCENTRATIONS IN AER NCBC TEST  
SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup> (CONCLUDED)

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
Phenanthrene	<1.0	<1.0
Dibenzo(a,h)anthracene	<2.0	<1.0
Indeno(1,2,3-c,d)pyrene	<2.0	<1.0
Pyrene	<1.0	<1.0

a. Analysis not made for benzidine dimethyl nitrosamine (N-nitrosodimethylamine) as listed in the modified PPL (see Appendix G); See Appendix S, Exhibit 3, for CAL data sheets.

b. Sample ID: HU-NCBC-R2-01; CAL Lab No: 21591-2

c. Sample ID: HU-NCBC-R2-02; CAL Lab No: 21413-3

d. Includes 2,4,5 isomer

e. Symbol (<) means not detected. Detection level value shown.

f. Estimated value.

g. Compounds co-elute--analyzed as a single compound.

TABLE 11. ORGANOCHLORINE PESTICIDE AND PCB CONCENTRATIONS IN AER  
DEVELOPMENT RUN SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup>

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
Aldrin	<0.05 <sup>d</sup>	<0.05 <sup>d</sup>
Alpha-BHC	<0.05	<0.05
Beta-BHC	<0.05	<0.05
Gamma-BHC (Lindane)	<0.05	<0.05
Delta-BHC	<0.05	<0.05
Chlordane	<1.0	<1.0
4,4'-DDD	<0.2	<0.2
4,4'-DDE	<0.1	<0.1
4,4'-DDT	<0.2	<0.2
Dieldrin	<0.1	<0.1
Endosulfan I	<0.1	<0.1
Endosulfan II	<0.1	<0.1
Endosulfan sulfate	<0.2	<0.2
Endrin	<0.1	<0.1
Heptachlor	<0.05	<0.05
Heptachlor epoxide	<0.05	<0.05
Toxaphene	<10.	<10.
PCB-1242	<1.0	<1.0
PCB-1248	<1.0	<1.0
PCB-1254	<1.0	<1.0
PCB-1260	<1.0	<1.0

a. Analysis was not made for endrin aldehyde, PCB-1016, -1221, and -1232 as listed in the modified PPL (see Appendix G); See Appendix S, Exhibit 3, for CAL data sheets.

b. Sample ID: HU-NCBC-R1-01; CAL Lab No: 21591-1

c. Sample ID: HU-NCBC-R1-02; CAL Lab No: 21413-2

d. Symbol (<) means not detected. Detection level value shown.

TABLE 12. ORGANOCHLORINE PESTICIDE AND PCB CONCENTRATIONS IN AER NCBC  
TEST SOIL FEEDSTOCK AND TREATED SOIL<sup>a</sup>

Compound	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
Aldrin	<0.03 <sup>d</sup>	<0.05 <sup>d</sup>
Alpha-BHC	<0.03	<0.05
Beta-BHC	<0.03	<0.05
Gamma-BHC (Lindane)	<0.03	<0.05
Delta-BHC	<0.03	<0.05
Chlordane	<0.67	<1.0
4,4'-DDD	<0.13	<0.2
4,4'-DDE	<0.07	<0.1
4,4'-DDT	<0.13	<0.2
Dieldrin	<0.07	<0.1
Endosulfan I	<0.07	<0.1
Endosulfan II	<0.07	<0.1
Endosulfan sulfate	<0.13	<0.2
Endrin	<0.07	<0.1
Heptachlor	<0.03	<0.05
Heptachlor epoxide	<0.03	<0.05
Toxaphene	<6.7	<10.
PCB-1242	<0.67	<1.0
PCB-1248	<0.67	<1.0
PCB-1254	<0.67	<1.0
PCB-1260	<0.67	<1.0

a. Analysis was not made for endrin aldehyde, PCB-1016, -1221, and -1232 as listed in the modified PPL (see Appendix G); See Appendix S, Exhibit 3, for CAL data sheets.

b. Sample ID: HU-NCBC-R2-01; CAL Lab No: 21591-2

c. Sample ID: HU-NCBC-R2-02; CAL Lab No: 21413-2

d. Symbol (<) means not detected. Detection level value shown.

TABLE 13. INORGANIC CONCENTRATIONS IN AER DEVELOPMENT RUN SOIL  
FEEDSTOCK AND TREATED SOIL<sup>a</sup>

Element	Concentration (ppm)	
	Soil Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>
Antimony	<3 <sup>d,e</sup>	<3 <sup>d,e</sup>
Arsenic	8.2	8.7
Beryllium	<0.3	0.42 <sup>f</sup>
Cadmium	<0.3	<0.3
Chromium	8.3	9.2
Copper	3.3	3.0
Lead	24 <sup>e</sup>	9.2
Mercury	<0.1	<0.1
Nickel	4.2	3.9 <sup>e</sup>
Selenium	<0.3 <sup>e</sup>	<0.3 <sup>e</sup>
Silver	<0.5 <sup>e</sup>	0.61 <sup>f</sup>
Thallium	<0.5 <sup>e</sup>	<0.5 <sup>e</sup>
Zinc	108	81
Total cyanide	<0.5	<0.5

a. See Appendix S, Exhibit 4, for CAL data sheets.

b. Sample ID: HU-NCBC-R1-01; CAL Lab No: 21591-1

c. Sample ID: HU-NCBC-R1-02; CAL Lab No: 21413-2

d. Not detected. Detection limit value shown.

e. Spike sample recovery was not within control limits.

f. Value was greater than or equal to the instrument detection limit but less than the detection limit required by contract.

TABLE 14. INORGANIC CONCENTRATIONS IN AER NCBC TEST SOIL FEEDSTOCK, TREATED SOIL, AND BAGHOUSE FILTER MATERIAL<sup>a</sup>

Element	Concentration (mg/kg or ppm)		
	Feedstock <sup>b</sup>	Treated Soil <sup>c</sup>	Baghouse Material <sup>d</sup>
Antimony	<3. <sup>e, f</sup>	<3. <sup>e, f</sup>	<3. <sup>e, f</sup>
Arsenic	5.5	6.4	1.3
Beryllium	<0.3	<0.3	<0.3
Cadmium	<0.3	0.34	3.8
Chromium	6.1	8.2 <sup>g</sup>	21
Copper	6.2	5.8	39
Lead	15. <sup>f</sup>	7.6	512
Mercury	<0.1	<0.1	0.4
Nickel	1.6	3.0	9.9
Selenium	<0.3 <sup>f</sup>	<0.3 <sup>f</sup>	<0.3 <sup>f</sup>
Silver	<0.5 <sup>f</sup>	0.58 <sup>f</sup>	2.2 <sup>f</sup>
Thallium	<0.5 <sup>f</sup>	<0.5 <sup>f</sup>	<0.5 <sup>f</sup>
Zinc	70	62	1260
Total cyanide	0.5	<0.5	<0.5

a. See Appendix S, Exhibit 4, for CAL data sheets.

b. Sample ID: HU-NCBC-R2-01; CAL Lab No: 21591-2

c. Sample ID: HU-NCBC-R2-02; CAL Lab No: 21591-3

d. Sample ID: HU-NCBC-R2-03; CAL Lab No: 21591-4

e. Not detected. Detection limit value shown.

f. Spike sample recovery was not within control limits.

g. Anomaly contributed to analysis.



<u>Compound</u>	<u>Development Runs (ppm)</u>	<u>NCBC Test (ppm)</u>
2,4,5/2,4,6-trichlorophenol	310.	55.
2,4-dichlorophenol	36.	10.
phenol	1.8 (est.)	3.4

The total analysis for 2,4-D and 2,4,5-T in both soil feedstock samples clearly shows the HO contamination (Table 15). Concentrations of 2,4,5-T were higher in both samples at 770 and 610 ppm.

In its creosote analysis of the two ITC feedstock samples, CAL found a variety of polynuclear aromatic hydrocarbons present. However, CAL concluded that "it is impossible to say that the creosote profile is present in the data" (Reference 18). This conclusion was based on the following reasoning. Low amounts of 2-methyl naphthalene and fluorene were present in one or both of the samples. CAL's creosote data showed that phenanthrene dominates anthracene by a factor greater than 6 to 1. This did not occur in the two samples. These data do not rule out the presence of creosote, but it is clear that the bulk of polynuclear and aromatic hydrocarbons came from other hydrocarbon sources. CAL decided that further analysis for only creosote was not possible (see Appendix S, Exhibit 6).

#### b. Treated Soil

Tables 7 and 8 compare the PCDD and PCDF results for the treated soil with the results for the feedstock for the development runs and NCBC test, respectively. The Battelle analysis data for sample HU-NCBC-R2-02 are included in Table 8 for comparison with the CAL data. The CAL data showed no detectable PCDD or PCDF except one isomer (2,3,7,8-TCDF) in the NCBC test sample at a concentration of 0.028 ppb. (Based on a review of the data, the positive identification is marginal because of signal-to-noise factors and should be considered as a maximum possible concentration, see discussion in Section V.A.3.a). However, some of the DLVs shown below (indicated by < symbol) for the total isomer

TABLE 15. CONCENTRATIONS OF HO CONSTITUENTS 2,4-D AND 2,4,5-T  
IN HUBER SAMPLES<sup>a</sup>

<u>Sample ID</u>	<u>CAL Lab No.</u>	<u>2,4-D (ppm)</u>	<u>2,4,5-T (ppm)</u>
<u>Feedstock</u>			
HU-NCBC-R1-01	21591-1	380	770
HU-NCBC-R2-01	21591-2	280	610
<u>Treated Soil</u>			
HU-NCBC-R1-02	21413-2	<1.0 <sup>b</sup>	<0.2 <sup>c</sup>
HU-NCBC-R2-02	21591-3	<0.01	<0.01
<u>Bagfilter Material</u>			
HU-NCBC-R2-03	21591-4	<0.01	<0.01
<u>Primary Carbon Filter</u>			
HU-NCBC-R1-09	21413-3	<0.01	<0.01
HU-NCBC-R2-09	21591-5	<0.01	<0.011
<u>Secondary Carbon Filter</u>			
HU-NCBC-R1-09A	21413-5	0.05	0.17
HU-NCBC-R2-09A	21591-6	<0.01	<0.01

a. See Appendix S, Exhibit 5, for CAL data sheet.

b. Not detected. Detection limit value shown.

results exceed the required 0.1 ppb. One factor influencing the high DLVs was the use of a low-resolution mass spectrometer in the analysis.

<u>Total PCDD/PCDF</u>	<u>Development Runs (ppb)</u>	<u>NCBC Test (ppb)</u>
TCDD	<0.057	<0.036
PCDD	<0.29	<0.18
HCDD	<0.24	<0.07
TCDF	<0.036	0.028
PCDF	<0.063	<0.019
HCDF	<0.015	<0.020
Sum	<0.70	<0.35

Even with the high DLVs, the sum of the six total isomer results for each sample showed that the PCDD/PCDF concentration in the treated soil was within the project goal of 1.0 ppb or less.

The Battelle analysis data for the NCBC test-treated soil sample (Table 8) show no detectable PCDD/PCDF concentrations, with DLVs for the isomers well below the required 0.1 ppb. The sum of the six total isomers for this sample shows a total PCDD/PCDF concentration less than 0.12 ppb. These results are superior to those from CAL. One reason is that Battelle used a high-resolution mass spectrometer in its analysis.

Only one semivolatile organic compound was detected at a concentration >1 ppm in either of the treated soil samples (Tables 9 and 10). This was di-n-butyl phthalate at 1.2 ppm in treated soil for the development runs. In the NCBC test-treated soil, the concentration for this compound was less than 1 ppm. The DLVs ranged from 1 to 5 ppm, which exceeds the requirement of 1 ppm. The analysis for organochlorine pesticides and PCBs showed similar nondetectable results obtained for the soil feedstock (Tables 11 and 12). DLVs were  $\leq 1$  ppm, except for toxaphene (10 ppm). Toxaphene is known to be difficult to analyze in soil types of matrices.

Tables 13 and 14 compare the inorganic analytical results for the treated soil samples with the soil feedstock results. Zinc remains highest at concentrations of 81 and 62 mg/kg (ppm), respectively. These

values represent reductions of 25 and 11 percent, respectively, compared to the feedstock concentrations. For the next highest concentration element lead, a significant reduction of 62 and 49 percent, respectively (from 24 to 9.2 ppm and 15 to 7.6 ppm), was shown. Other detectable elements showed similar concentrations as the feedstock. Because the concentrations were sufficiently low in the treated soil, an EP toxicity test was not performed. The basis for this is discussed further in Section V.B.5.

The HO constituents 2,4-D and 2,4,5-T were not detectable in either of the treated soil samples (Table 15). Detection limit values were 1 ppm or less.

c. Baghouse Particulate Material

The baghouse filter particulate material (sample HU-NCBC-R2-03) showed detectable TCDD (0.87 ppb), TCDF (0.54 ppb), and PCDF (0.29 ppb) (Table 16). The detection limit value for HCDF was less than the required 0.1 ppb; however, the DLVs for PCDD and HCDD exceeded the requirement at 0.47 and 0.26 ppb, respectively.

Ten semivolatile organic compounds were detected in the baghouse particulate material sample (Appendix S, Exhibit 3 data sheets):

<u>Compound</u>	<u>Concentration (ppm)</u>
Pyrene	47
Acenaphthylene	36
Fluoranthene	33
Naphthalene	18
Phenanthrene	13
Anthracene	2
Benzo (b) fluoranthene	1.7
Benzo (k) fluoranthene	1.7
Fluorene	1.3
Di-n-butyl phthalate	1.2

Threshold limit values ranged from 1 to 5 ppm, which exceeds the required DLV of 1 ppm. None of these organic compounds was detected in the soil feedstock, with DLVs of 1 and 4 ppm (see Tables 9 and 10). Assuming the

TABLE 16. POLYCHLORODIBENZO-P-DIOXIN AND POLYCHLORODIBENZOFURAN  
CONCENTRATIONS IN AER NCBC TEST BAGHOUSE FILTER  
AND ACTIVATED CARBON FILTER MATERIALS<sup>a</sup>

PCDD/PCDF	Concentrations (ppb)		
	Baghouse Filter <sup>b</sup>	Primary Carbon Filter <sup>c</sup>	Secondary Carbon Filter <sup>d</sup>
<u>Dioxins</u>			
Total TCDD	0.87	<0.013 <sup>e</sup>	<0.018
2,3,7,8-TCDD	0.49 <sup>f</sup>	<0.013 <sup>g</sup>	<0.018 <sup>h</sup>
Total PCDD	<0.47 <sup>e</sup>	<0.15	<0.27
1,2,3,7,8-PCDD	--	<0.15	<0.27
Total HCDD	<0.26	<0.043	<0.058
1,2,3,4,7,8-HCDD	--	<0.043	<0.058
<u>Furans</u>			
Total TCDF	0.54	<0.0034	<0.0075
2,3,7,8-TCDF	--	<0.0034	<0.0075
Total PCDF	0.29	<0.013	<0.021
1,2,3,7,8-PCDF	<0.033	<0.013	<0.021
2,3,4,7,8-PCDF	<0.033	<0.013	<0.021
Total HCDF	<0.074	<0.025	<0.033
1,2,3,4,7,8-HCDF	--	<0.025	<0.033

a. See Appendix S, Exhibit 2, for CAL data sheets

b. Sample ID: HU-NCBC-R2-03; CAL Lab No: 21591-4RX\$

c. Sample ID: HU-NCBC-R2-09; CAL Lab No: 21591-5

d. Sample ID: HU-NCBC-R2-09A; CAL Lab No: 21591-6

e. Symbol (<) means not detected. Detection level value shown.

f. Percent accuracy <sup>37</sup>Cl-TCDD = 101 percent. Results includes isomer 1,2,3,4-TCDD, which is likely a small amount by comparison to the 2,3,7,8-TCDD isomer contribution. Used enhanced software to determine value.

g. Percent accuracy <sup>37</sup>Cl-TCDD = 91 percent

h. Percent accuracy <sup>37</sup>Cl-TCDD not stated on CAL data sheet

data are correct, their existence would be the result of recombination from destructed components during pyrolysis. Pyrolysis at oxygen-deficient conditions, such as in the AER process, may build higher-order organic compounds. The recombination would occur near the end of the high temperature process where there is insufficient time for the new organic compound to be destroyed. Because these compounds were not detected in the treated soils (Tables 9 and 10), the organics must volatilize at the high temperature, transport in the exhaust, and later condense on the aerosol particles as the exhaust temperature reduces. Analytical error is also possible; however, because the values for five of the organics are quite high compared to results in other samples, this reason is unlikely.

None of the organochlorine pesticides or PCBs was detected, with DLVs similar to those previously discussed for the soil samples.

Inorganic concentrations in the baghouse filter material (sample HU-NCBC-R2-03) are presented in Table 14 for comparison with concentrations in the NCBC test soil feedstock and treated soil. Large concentrations of zinc (1260 ppm) and lead (512 ppm) are indicated. Other detected elements (in descending order of concentration) were copper (39 ppm), chromium, nickel, cadmium, silver, arsenic, and mercury (0.4 ppm).

The HO constituents 2,4-D and 2,4,5-T were not detectable in the filter material (Table 15). The DLVs were 0.01 ppm.

#### d. Activated Carbon Filter Material

No dioxins or furans were detected in the primary and secondary activated carbon filter materials sampled after the NCBC test (samples HU-NCBC-R2-09 and -R2-09A, Table 16). The DLVs were less than 0.1 ppb in all cases, except for total PCDD in each sample where the DLV ranged from 0.15 to 0.27 ppb.

No semivolatile organic compounds, organochlorine pesticides, and PCBs were detected in either of the samples (see CAL data

sheets in Appendix S, Exhibit 3). The DLVs for these analyses were 1.0 ppm or less, as required.

Inorganic analysis results for the primary carbon filter material (after the development run and NCBC test samples) and second carbon filter material (after NCBC test) are shown in the CAL data sheets in Appendix S, Exhibit 5. Zinc has the highest concentration at 19, 16, and 14 ppm in the three respective samples. Lead had the next highest concentration. Other elements detected showed similar results in all three samples.

HO constituents 2,4-D and 2,4,5-T were not detected in the two primary carbon filter samples (HU-NCBC-R1-09 and R2-09), with DLVs at 0.01 ppm (Table 15). These compounds were detected in the secondary carbon filter material sample (HU-NCBC-R1-09A) following the development runs at concentrations of 0.05 and 0.17 ppm, respectively. However, the material sample taken following the NCBC test (HU-NCBC-R2-09A) showed no detectable amounts with DLVs of 0.01 ppm. The positive indications in sample HU-NCBC-R1-09A are questioned for the following reasons. The primary carbon bed filter is upstream in the flow path to the secondary carbon filter and shows a DLV of 0.01 ppm for the same run. The secondary carbon filter was not changed between the development runs and the NCBC test; hence, the sample results for the post-NCBC test should be of equal or greater magnitude. These latter results show a DLV of 0.01 ppm for both 2,4-D and 2,4,5-T, which is more realistic for downstream sampling.

e. Ambient Air Filters

The 12 ambient air filter samples were analyzed for 2,3,7,8-TCDD (specific) and total suspended particulates (TSP). Calculated average concentrations for the individual sample times are shown in Table 17.

TABLE 17. SUMMARY OF 2,3,7,8-TCDD AND TOTAL SUSPENDED PARTICULATE CONCENTRATIONS IN AMBIENT AIR FILTER SAMPLES<sup>a</sup>

Run	HV Sampler <sup>b</sup>	Sample Number	Air Volume (m <sup>3</sup> )	2,3,7,8-TCDD		TSP Concentration (µg/m <sup>3</sup> )
				Quantity (ng)	Concentration <sup>b</sup> (µg/m <sup>3</sup> )	
1	1	EE-NCBC-R1-01	4846	<0.59 <sup>c</sup>	<0.12 <sup>c</sup>	18.6
	2	EE-NCBC-R1-02	4636	<0.27	<0.06	44.9
	3	EE-NCBC-R1-03	4846	1.5	0.31	36.4
	4	EE-NCBC-R1-04	2877	<0.17	<0.06	17.4
2	1	EE-NCBC-R2-01	4562	<0.14	<0.03	26.8
	2	EE-NCBC-R2-02	4637	<0.28	<0.06	31.8
	3	EE-NCBC-R2-03	4562	<0.22	<0.05	25.1
	4	EE-NCBC-R2-04	4735	<0.37 <sup>d</sup>	<0.08 <sup>d</sup>	24.3
3	1	EE-NCBC-R3-01	1761	<0.13	<0.07	41.9
	2	EE-NCBC-R3-02	1596	<0.28 <sup>d</sup>	<0.18 <sup>c</sup>	38.5
	3	EE-NCBC-R3-03	1761	1.1	0.62	55.7
	4	EE-NCBC-R3-04	1829	<0.12	<0.07	35.8

a. See Appendix S, Exhibit 7, for CAL data sheet.

b. See sampler location layout in Figure 15.

c. The symbol (<) means not detected. Detection limit value shown.

d. Data shown represent change from CAL data sheet because of signal-to-noise criteria. See data review discussion in Section V.A.3.a.

Results for the onsite area Sampler 3 during runs 1 and 3 show a low, observable amount of TCDD in the atmosphere in the vicinity of area activity during operations. TCDD quantities in each sample were 1.5 and 1.1 ng, respectively. Corresponding average air concentrations were calculated to be 0.31 and 0.62 pg/m<sup>3</sup>. The third result for Sampler 3, during Run 2, had a DLV of 0.05 pg/m<sup>3</sup>. By comparison, onsite



control Sampler 2 showed only one detectable result at  $0.07 \text{ pg/m}^3$  during Run 3. The other two samples show DLVs of  $0.06 \text{ pg/m}^3$ .

Downwind offsite area Sampler 4 showed one detectable 2,3,7,8-TCDD result at  $0.03 \text{ pg/m}^3$  during Run 3. This data point is essentially in the noise level because the other two samples had DLVs of 0.06 and  $0.07 \text{ pg/m}^3$ . By comparison, the three samples for upwind control sampler 1 were all undetectable at TCDD DLVs in the range of 0.03 to  $0.12 \text{ pg/m}^3$ . These data indicate no detectable 2,3,7,8-TCDD impact offsite because of the demonstration tests and associated activities.

The average TSP concentrations for the 12 samples ranged from  $17.4$  to  $55.7 \text{ mg/m}^3$  (Table 17). The highest concentration was obtained by the onsite area sampler during Run 3 (sample HV-EE-NCBC-R3-03). Only during Run 1 did the onsite area activity sample results differ substantially from the upwind control and downwind offsite data; and, in this case, the onsite control result was actually greater than the area sample result. The results indicate that the demonstration tests and associated activities did not cause any significant increase of TSP in the local atmosphere.

## B. EVALUATION

### 1. System Mass Balance

The process output mass was calculated to be 98.3 percent of the process input mass for the development runs and the actual test. As shown in Table 18, this comparison is based on the soil treated during both the development runs and the actual test. Individual run mass balances could not be performed because the collection bin containing the treated soil was not removed from the system until all tests were completed. The carbon monoxide and carbon dioxide discharges were estimated by using the fixed gas analysis (see Section V.C.3) to determine relative concentrations in the flue gas. Better closure could have been realized by using more accurate scales, accounting for solids obtained for analytical analysis

TABLE 18. MASS BALANCE FOR AER3 DEVELOPMENT RUNS AND NCBC TEST

<u>Description</u>	<u>Value<sup>a</sup> (lb)</u>
<u>Mass entering system</u>	
Soil treated during development runs	142
Soil treated during actual test	962
Soil treated for all tests	1104
<u>Mass exiting system</u>	
Treated soil collected	941
Bagfilter material collected	11.4
CO/CO <sub>2</sub> discharged during development runs	14.7 <sup>b</sup>
CO/CO <sub>2</sub> discharged during actual test	118 <sup>b</sup>
Total mass exiting system	1085
Mass unaccounted for <sup>c</sup>	19

a. Weights of solids measured by field scale.

b. Average CO and CO<sub>2</sub> concentrations in the flue gas were 1.2 and 4.0 percent, respectively.

c. System mass balance closure is 98.3 percent. Moisture in exiting flue gas was not measured.

(all weights were obtained after analytical samples were taken), and measuring moisture in the exiting flue gas. Moisture content measured by ITC in the two soil feedstock samples was 10.003 and 0.60, which can account for some of the difference (see Section IV.B.2). However, the closure achieved is considered to be a very good system mass balance.

## 2. Dioxin/Furan Reduction

Analysis of the feedstocks used in the AER3 development runs and the NCBC test showed that substantial reduction occurred during soil preparation. The sample average for soil collected in the five ITC feedstock drums was 250 ppb 2,3,7,8-TCDD (Section IV.B.1). Soil drying before crushing probably reduced the 2,3,7,8-TCDD, as indicated by the development and NCBC test feedstock samples (193 and 111 ppb, respectively, see Section IV.A.4.a). Release of the dioxins to the environment was prevented by off-gasing through an activated carbon filter. This illustrates the need to incorporate environmental controls on any soil preparation treatment step in which heating of the material is required.

The ability of the AER3 to demonstrate numerical dioxin/furan reduction in the soil is largely restricted by the detection level capability of the GC/MS equipment. Only one case analyzed by CAL showed a detected level, which was for the total TCDF in treated soil from the NCBC test. This result was 0.028 ppb compared to the feedstock data of 12.7 ppb (TCDF). This TCDF result in the treated soil was considered to be a maximum possible concentration (see data review, Section V.A.3.a). Battelle analysis showed a DLV = 0.01 ppb for TCDF in a split of the sample by using high-resolution equipment. Comparing CAL data for 2,3,7,8-TCDD in the feedstock (111 ppb) with the DLV for the treated soil from the NCBC test (0.036 ppb) shows even greater reduction of a more toxic compound. The Battelle data (DLV = 0.04 ppb) for the treated soil agrees with the CAL data. Although all isomers were not analyzed by CAL at DLVs  $\leq 0.1$  ppb, the total for the six groups of dioxins and furans is less than 1 ppb in each treated soil sample. Adding the DLVs for the six groups of the development run soil gives 0.84 ppb as an upper bound. Adding the TCDF value and the other five DLVs of the NCBC test soil gives better results at 0.35 ppb. The Battelle data for the NCBC test-treated soil are even better at 0.12 ppb. These results show that the AER pyrolysis process can meet the 1 ppb criteria.

### 3. Phenol-Type Compound Reduction

Two semivolatile compounds (2,4,5/2,4,6-trichlorophenol and 2,4-dichlorophenol) were indicated in varying concentrations in the two feedstock samples (55, 310 and 10, 36 ppm, respectively). The AER3 pyrolysis process reduced the levels below the DLVs, which were 1 ppm for each compound. Lack of detection of other semivolatile organic compounds, any organochlorine pesticides, and PCBs in the feedstock precluded evaluation of the destructive capability of these compounds by the pyrolysis process.

### 4. Inorganics

The inorganic analytical results show zinc and lead concentrations in the treated soil to be substantially less than those in the soil feedstock. Substantial concentrations of zinc and lead were observed in the baghouse filter material. Although chromium, arsenic, copper, and nickel were detected in the baghouse filter material, their levels in the feedstock and the treated soil were not significantly different. Mercury, which was previously undetected in the feedstock and treated soil samples, was detected in the baghouse filter material. When the soil is treated in the AER, zinc, lead, and other elements are vaporized. The melting point for each of the elements listed in Table 14 is below the 3650 °F operating temperature of the AER3 during the NCBC test. Zinc and lead have especially low melting points (788 and 621 °F, respectively) by comparison, making them more likely to remain vaporized through cooldown in the PRTZ. The high concentrations of these two elements in the baghouse material indicate this to be the case.

Because the analysis performed on the treated samples was a bulk process, the preferential position of the inorganics relative to particle composition is unknown. If located within the glass-like surface, the inorganics are more resistant to leaching. However, because condensing vapors tend to form film on the particle surface, the inorganics are more susceptible to leaching.

Inorganics were detected in the carbon filters. The concentrations are due to impurities in the charcoal for the following reasons. The baghouse filter is located ahead of the carbon filters. The exposure time was much greater for the NCBC posttest sample of the primary filter compared to the sample taken after the second development test run, yet the zinc concentration was the same (14 ppm). Also, the NCBC posttest secondary and primary carbon filter samples showed the same concentrations (14 ppm), although one is ahead of the other.

## 5. Hazardous Waste Characteristic Assessment

One objective of the NCBC test was to show that AER treated soil could be delisted as hazardous waste. To assess this, the treated soil was examined according to EPA's four hazardous characteristics listed in 40 CFR Part 261.2 (ignitability, corrosivity, reactivity, and EP toxicity.) Battelle data presented in this report have established that 2,3,7,8-TCDD was removed from the treated soil (to less than 1 ppb TCDD and total isomers). Other organic priority pollutants found in the feedstock were removed as well. The data review concluded that, although the data could not be strictly validated, they could be used to evaluate the effectiveness of the process. For actual soil restoration use by the AER technology, confirming tests would be necessary to show that the treated soil could meet delisting criteria.

Discussed below is an evaluation of the treated soil compared to the four EPA hazardous characteristics.

### a. Ignitability

The objective of examining the ignitability characteristic is to identify substances that either present fire hazards under routine storage, disposal, and transportation, or are capable of contributing to a fire once started. The treated soil does not possess either of these characteristics because it can neither start nor sustain combustion.

b. Corrosivity

The corrosivity characteristic, defined in 40 CFR Part 261.22, is intended to identify substances that might pose a hazard to human health or the environment because of their ability to:

- o Mobilize toxic metals if discharged in a landfill
- o Corrode handling, storage, transportation, and management equipment
- o Destroy human or animal tissue in the event of inadvertent contact.

In 40 CFR 261.22, EPA specifies two properties that define a corrosive substance: pH and corrosivity toward Type SAE 1020 steel. A substance is defined as corrosive if:

- o It is aqueous and has a  $\text{pH} \leq 2$  or  $\geq 12.5$ , as determined by a pH meter, using either EPA Test Method 9040 or an equivalent test method approved by the EPA Administrator under the procedure set forth in 40 CFR Parts 260.20 and 260.21.
- o It is a liquid and corrodes steel (SAE 1020) at a rate  $> 6.35 \text{ mm/yr}$  at a test temperature of  $131^\circ\text{F}$ , as determined by the test method specified in NACE (National Association of Corrosion Engineers) Standard TM-01-69 as standardized in Method 1110 or an equivalent test method approved by the EPA Administrator under the procedures set forth in 40 CFR Parts 260.20 and 260.21.

These procedures are clearly oriented toward aqueous substances and therefore do not apply to treated soil.

c. Reactivity

EPA regulation 40 CFR Part 261.23 defines reactive substances as those that have any of the following properties:

- o Readily undergo violent chemical change
- o React violently or form potential explosive mixtures with water
- o Generate toxic fumes when mixed with water or, in the case of cyanide or sulfide-bearing wastes, when exposed to mild acidic or basic conditions
- o Explode when subjected to a strong initiating force
- o Explode at normal temperatures and pressures
- o Fit within the U.S. Department of Transportation's forbidden explosives, Class A explosives, or Class B explosives classifications.

Because of the extremely inert quality of the treated soil, it does not meet any of these criteria and is therefore not a reactive substance.

d. Extraction Procedure Toxicity

The extraction procedure (EP) is designed to simulate the leaching a substance will undergo if disposed in a sanitary landfill. It is a laboratory test in which a representative sample of waste (100 grams) is extracted with distilled water maintained at a pH of 5 using acetic acid. The EP extract is then analyzed to determine if any of the thresholds established for the eight elements (arsenic, barium, cadmium,

chromium, lead, mercury, selenium, silver), four pesticides (Endrin, Lindane, Methoxychlor, Toxaphene), and two herbicides (2,4,5-trichlorophenoxypropionic acid, 2,4-dichlorophenoxyacetic acid) have been exceeded. If the EP extract contains any one of the above substances in an amount equal to or exceeding the levels specified in 40 CFR Part 261.24, the substance possesses the characteristic of EP toxicity and is a hazardous waste.

As shown in Table 19, even under the most extreme conditions, the EP extract would never contain amounts of the listed elements, pesticides, and herbicides equal to or above the threshold limitations set forth in 40 CFR Part 261.24. Table 19 also summarizes calculations that predict the maximum amount of elements that could possibly appear in the EP extract, assuming that all elements detected go into solution. None of the pesticides or herbicides cited above was detected in the treated soil.

Barium is not listed on the modified PPL (see Appendix G); thus, its concentration was not determined during the CAL analysis. Before a formal delisting of the treated soil could occur, analytical determination of the barium concentration would be necessary. However, additional evidence suggests that an excessive concentration of the element would not be expected. Because of the high lead concentration, CAL ran an EP toxicity test of the baghouse filter material in accordance with EPA Method 1310 (see Appendix V for results). Barium was detected at 0.75 mg/L in the leachate, well below the EPA limit of 100 mg/L. Barium volatilizes like most of the inorganics, which explains its appearance in the baghouse material; however, its low concentration compared to the limit suggests that treated soil concentrations would also be safe. Review of Battelle Columbus Laboratories data for "clean" NCBC soil samples (40196 53-2 and 53-3, see Appendix W) from the NCBC sampling program shows that the seven other elements in the native soil have concentrations equal to or greater than those shown in Tables 13 and 14 for the Huber feedstock or treated soil samples. This further supports the premise that an unusually high concentration of barium would not be expected.



TABLE 19. CONCENTRATIONS OF ELEMENTS IN TREATED SOIL EP EXTRACT ASSUMING COMPLETE EXTRACTION

a Element	Concentrations in Treated Soil b (mg/kg)	Maximum Concentration in EP Extract (mg/L)	EPA Threshold Limitation (mg/L)
Arsenic	6.4	0.320 <sup>c</sup>	5.0
Barium	NT <sup>d</sup>	NT <sup>d</sup>	100.0
Cadmium	<0.3	0.015	2.0
Chromium	8.2	0.410	5.0
Lead	7.6	0.380	5.0
Mercury	<0.1	<0.005	0.2
Selenium	<0.3	<0.015	1.0
Silver	0.58	0.029	5.0

a. None of the pesticides or herbicides specified in 40 CFR Part 261.24 was detected in the treated soil, see Tables 11, 12, and 15.

b. See Table 14 for concentrations.

c. Sample calculation for arsenic in EP extract assuming complete extraction:

d. NT = Not tested.

$$100\text{-gram sample} \times 6.4 \text{ mg/kg} = 0.64 \text{ mg}$$

0.67 mg of arsenic dissolved in 2 L of solution results in a concentration of:

$$\frac{0.64 \text{ mg}}{2 \text{ L}} = 0.32 \text{ mg/L}$$

e. Restoration of AER Process-Treated Soil

Because the treated soil is not corrosive, ignitable, or reactive and because it passes the requirements for the EP toxicity test, dioxin-contaminated soil treated by the AER process can satisfy requirements in 40 CFR 261.2 for restoration use.

This evaluation was performed based on the regulations existing at the time of the demonstration. In July 1985, the dioxin and furan compounds became an RCRA listed waste. The Federal Register dated November 7, 1986, (Reference 22) requires the following:

- a. Contamination > 1 ppb dioxins requires treatment
- b. Treated material < 1 ppb requires a toxicity characteristic leaching procedure (TCLP) analysis (Appendix I to 40 CFR 268).
- c. Material meeting these criteria can be disposed of in a Class C landfill or be delisted.

Any delisting effort would also require an assessment of Appendix VIII to 40 CFR 261 for hazardous constituents and perform an evaluation of the EPA vertical-horizontal-subsurface model, as specified in the Federal Register dated November 27, 1985 (Reference 23). Although these analyses were not performed on the AER technology, it is reasonable to expect that the treated material could meet the requirements. Because the full requirements for delisting the material with EPA are somewhat uncertain, application of any technology must be judged against the regulations that apply at the time.

## 6. Recombination Organic Compounds

The semivolatile organic compound analysis of the baghouse filter material sample suggests that organic compounds recombined during the pyrolysis process and these organics were released in the exhaust. The major compounds measured were pyrene, acenaphthylene, fluoranthene, naphthalene, and phenanthrene. Each is on the PPL. None was detected in treated soil samples. This indicates that any such organics continue in the exhaust stream. The baghouse material results indicate that the organic vapors condense on the aerosol particles for collection in the filter. The extent of remaining organic vapors passing on through to the activated carbon filters is unknown. None of these organic compounds was detected in the carbon filter samples; however, extraction of these compounds from carbon material is extremely difficult and may be the reason. These results indicate the need for mitigating features being installed in the exhaust line from the reactor. The use of a baghouse filter backed up by activated carbon filters should be sufficient. However, downstream effluent analysis may be desirable to ensure adequacy of the mitigating features.

The baghouse filter material becomes hazardous waste because it collects these organic priority pollutants. Several solutions are available. One is to slow down the feed rate to increase the residence time. A second is to reprocess the baghouse material as feedstock to the reactor. A third is to assume that the collected material is sufficiently small to send it separately to a hazardous waste disposal site.

The possibility of recombination of organic compounds during the AER pyrolysis process needs to be further investigated. However, these results provide an awareness for future planning.

## 7. Problems Encountered

Several problems were encountered during preparation of the 1100 pounds of NCBC soil. Almost all can be attributed to the use of bench-scale equipment in a field application. Because this test was

intended to demonstrate AER's effectiveness in treating soil containing HO, very little emphasis was placed on optimizing soil pretreatment (only readily available equipment was used). Although problems were experienced with the jaw crusher and screener, they were both related to wear and tear, and were repaired immediately. The pulverizer never worked properly. When soil was being fed, the plates bound up and threw the breaker. An analysis of the soil revealed that it contained small pieces of metal which, according to Bico (the manufacturer of the pulverizer), was responsible for the problem.

The extremely small geometry of the AER3 presented soil processing problems while treating the NCBC soil. The AER3 was built with the intention of performing brief demonstrations and proof-of-concept experiments. Precise alignment of the feed stream as it passed through the reactor was difficult and resulted in accumulation of melted soil at the exit of the reactor. These problems are not experienced in the larger AER12. During the EPA/PCB trial burn, performed in September 1983 on the AER12, 7 tons of soil were treated with no problems (Reference 13). Similar results were observed during the  $\text{CCl}_4$  tests (Reference 14) and during several endurance runs performed by Huber. Although the soil is partially melted during treatment, the AER12 generates a much better blanket than the AER3, thus preventing contact with the reactor core wall. As the soil falls through the water-cooled PRTZ (Figure 6), it is solidified before collection in the solids collection bin.

Before the NCBC tests, Huber performed several tests in Borger, using a surrogate soil believed to be similar to the NCBC soil. The NCBC soil, however, had a much lower melting point than the surrogate soil. To mitigate this problem, the reactor temperature was lowered to 3600 °F, which is 500 °F lower than the planned operating temperature. Even though the reactor operated at 3600 °F, which is significantly lower than the planned AER operating temperature of 4100 °F, all test objectives were met (i.e., all solids were treated to less than 1 ppb total dioxins and furans). In commercial operation, the reactor temperature would probably be maintained above 3600 °F.

As mentioned earlier, two batches of soil were prepared for use as feedstock in the tests. As presented in Section IV.B.2, in-process samples, obtained by Huber and analyzed by ITC, revealed that the 2,3,7,8-TCDD concentration of Sample 1 was 145 ppb and Sample 2 was 353 ppb. Samples were obtained from batch 1 after supplemental drying. The sample from batch 2 was obtained before using supplemental drying. The moisture contents associated with the two samples suggest that Sample 1 is from batch 1 and Sample 2 is from batch 2 (the moisture content for batch 1 is 0.03 percent and for batch 2 is 0.6 percent). It is believed that as the soil was being dried (using the supplemental drying system), some of the dioxin on the first batch vaporized off the soil and was deposited on the activated carbon. The supplemental drying temperature for batch 2 was consequently lowered. The soil temperature during supplemental drying was not specifically monitored and was controlled via a setpoint on the electrical drum heaters. Apparently, lowering the supplemental drying temperature still resulted in some dioxin vaporizing off the soil since CAL's analysis of the feed soil (for both the development runs and actual test) was also low compared to the feed soil analyzed by ITC.

## SECTION VI

### COST ESTIMATING FOR FULL-SCALE APPLICATION OF AER TECHNOLOGY

This section presents the cost estimate for process equipment transportation and the excavation, soil preparation, and treatment of 20,000 tons of TCDD-contaminated soil, which represent the conditions at NCBC. Based on measured density of NCBC soil,\* the equivalent excavation volume is approximately 18,800 yd<sup>3</sup> and is derived from excavating 18 acres of soil from the NCBC site to a depth of about 8 inches. This volume is used as the reference case even though more recent soil analysis (Reference 11) indicates that less remedial action will be needed to satisfy criteria. Treatment of the contaminated soil will be assumed using the AER process developed by the J. M. Huber Corporation.

The cost-estimating procedure is identical to that normally used by CH<sub>2</sub>M Hill, Inc., and relies heavily on the cost history obtained at recent excavations of TCDD-contaminated soil in the state of Missouri. The reference case relates to site-specific conditions existing at the NCBC storage site. In addition, a sensitivity analysis assessing the effect on the cost estimate of variation in specific assumptions or variables is presented. These variables are soil quantity (including influence of process rate), geographic location, and AER variable costs (labor, power, transportation, and capital).

Many of the costs identified in this estimate are common to any thermal treatment alternative, whether it is AER, rotary kiln, infrared heat, etc. These costs are dictated by site characteristics, regulations, physical handling, and other constraints, and are largely independent of the treatment process used. Costs are segregated into those fixed and variable cost elements associated with the AER treatment process, and those associated with the necessary ancillary site work. This cost estimate, therefore, separates costs into four basic categories:

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\*. The "NCBC as received" measured density for Sample 4768 is 78.92 lb/ft<sup>3</sup> (see Volume III of ITC's technology report for NCBC). All weights are presented on this as excavated condition.

1. Common remedial costs
2. Common site operating and monitoring costs
3. AER setup
4. AER facility operating and maintenance costs.

Most of this section is based on input from J. M. Huber Corporation, who contracted the engineering firm CH<sub>2</sub>M Hill. To present these data, this section consists of six parts:

1. Remedial action approach
2. Scaleup technical basis
3. Cost-estimating approach and basis
4. Cost estimate
5. Sensitivity analysis
6. Discussion of cost estimate, including independent validation.

#### A. REMEDIAL ACTION APPROACH FOR REFERENCE CASE

1. Overall Remedial Description

At the site, 20,000 tons of TCDD-contaminated soil will be excavated and transported to the soil treatment facility in sealed bins. The soil will be fed through the soil preparation treatment plant at a rate of about 67 tons/day to match the AER18 treatment rate. Both facilities are intended to operate around the clock on a 7-day work week and manned by four shift crews. Equivalent AER18 feed rate on this basis is 93 lb/min.

At least 1 week's feedstock of 470 tons is planned to be maintained in a sealed bin and stored onsite as a buffer for continuous operation of the AER. After AER treatment, the delisted treated soil will be cooled, analyzed, and temporarily stored in sealed bins before onsite disposal in the same area from which it was taken.

The AER equipment and soil treatment facility will be contained within a process operating area of about 150 by 150 feet. Huber will be responsible for the mobilization, operation, and demobilization of all equipment within these limits. The site preparation for the process operating area and all activities outside this area are assumed to be the responsibility of the Department of Defense (or its agent).

## 2. Assumed Site Conditions

The reference waste site is assumed to be the HO-contaminated NCBC site area at Gulfport, Mississippi. Weather at the site ranges between 60-90 °F for the daily high and 45-75 °F for the daily low. Mean windspeed is approximately 12-15 mph; however, tropical storms and hurricanes occur frequently in this coastal region. A rainy season from July to September will average about 6.5 inches of rain each month. The average annual rainfall for this area is about 60 inches/year.

These conditions should enable year-round excavation, soil preparation, and AER treatment, with only a minor amount of soil stored onsite to allow for storms and holidays. The mild climate will also avoid problems associated with handling frozen soil and building heating.

The terrain is flat (see Figure 3). The site soil is sand to sandy loam, intermixed with some clay. Additionally, it has been stabilized with cement and is interspersed with asphalt and shale. The water table is approximately 4 to 6 feet below the land surface. For this report, it was assumed that (1) soil excavation/handling is possible with conventional equipment, (2) there are no access problems, and (3) groundwater contamination is not a problem.



## B. SCALEUP TECHNICAL BASIS

### 1. Scaleup Size AER

Huber has demonstrated experience from the OCDD side-by-side tests at the Borger facility in scaling from the 3-inch-diameter AER3 to the 12-inch-diameter AER12 (Reference 15). In addition, the operating parameters for the AER12 were extended during the  $\text{CCl}_4$  testing (Reference 14). Using this experience and the critical scaling factors with actual operating data, scaling from an AER12 to an AER18 can be accomplished with reasonable confidence. Discussed below are the major parameters and methods to be considered.

#### a. Core

The reactor core is scaled by holding a constant length-to-diameter ratio of 12 to 1. The AER3 has a length of 3 feet and a diameter of 3 inches, and the AER12 has a length of 12 feet and a diameter of 12 inches. Therefore, the AER18 will utilize a core with a length of 18 feet and a diameter of 18 inches.

#### b. Feed Rate

Based on published data from the  $\text{CCl}_4$  testing (Reference 14), a feed rate factor of  $1.1 \text{ lb/min-ft}^2$  of heated core surface area with the AER12 has been demonstrated. Scaling up by this factor, the AER18 is projected to operate at a feed rate of about 93 lb/min, which meets the feed rate discussed in Section V.A.1. From its experience with the AER12, Huber feels that a higher feed rate factor ( $1.9 \text{ lb/min-ft}^2$ ) can be processed with commercial-sized units. This would provide a feed rate of 168 lb/min; however, the soil preparation facility would be a limiting factor as presently conceived (see Section VI.B.2).

c. Electrical Power Requirements

Electrical power requirements should approximate AER12 experience at 0.5 kWh/lb of treated soil, assuming heat losses are kept proportional to the core surface area. The AER3 experience at NCBC was nominally 1.2 kWh/lb of treated soil (Table 3); however, this unit has a water-cooled metal jacket to house the reactor, which explains the higher factor. The commercial-sized AER, like the AER12, would not include this heat sink. Utilization of more efficient insulation and process heat for nitrogen heating can be factored into the requirements, thus reducing the energy needs.

d. Nitrogen

Nitrogen needs are also scaled according to heated core surface area. From its experience with the AER12, Huber feels that as little as  $2.4 \text{ sft}^3/\text{min-ft}^2$  nitrogen flow rate will be sufficient at operating conditions. Based on published data from the  $\text{CCl}_4$  testing (Reference 14), a nitrogen flow rate factor of  $2.8 \text{ sft}^3/\text{min-ft}^2$  has been demonstrated, which is only a difference of about 14 percent. Therefore, assuming these scaling factors apply for AER18, the projected and field-demonstrated nitrogen flow rates would be approximately 200 and  $230 \text{ sft}^3/\text{min}$ , respectively.

e. Other Equipment

Other equipment such as material handling, scrubbers, piping, baghouse filters, and activated carbon filters will be designed according to standard engineering practices.

2. Soil Preparation

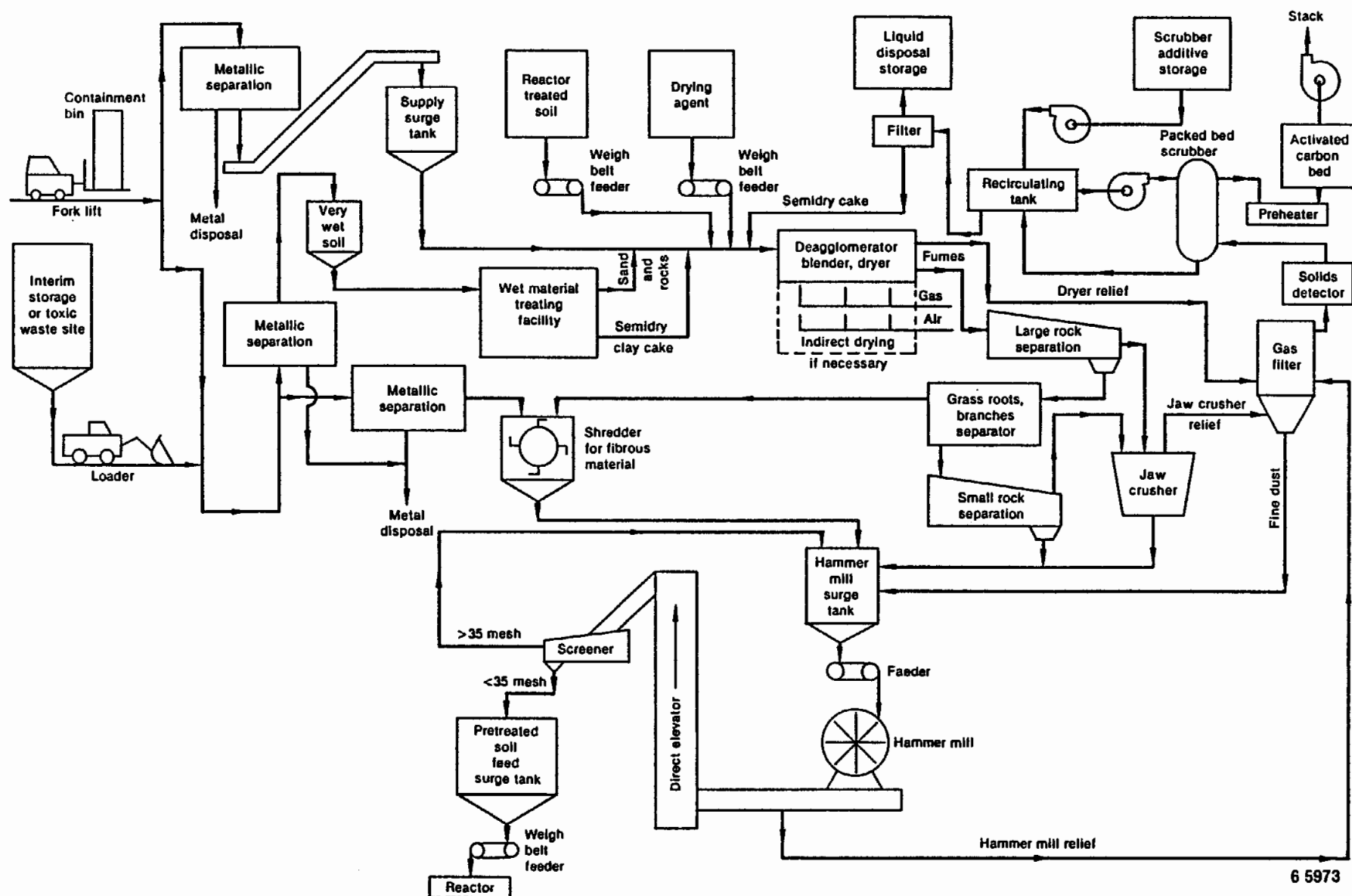
Soil preparation equipment used during the AER3 tests that produced several problems (see Section V.B.7) would not be used for a full-scale operation. Rather, a soil pretreatment facility would be

employed like one designed by the Ralph M. Parsons Company, a leading engineering firm in materials handling equipment design. Appendix X presents a complete description of the reference facility. Figure 17 provides a flow schematic.

The reference soil pretreatment facility can prepare a wide variety of contaminated soils for treatment in the AER. The system can crush, blend, dry, pulverize, and size a variety of composite soils of sizes up to 10 inches across and with a moisture content up to 30 percent to produce a ground free-flowing material that will pass through a 35-mesh screen. The soil processing rate is 3 tons/hour. On a round-the-clock basis over a 7-day work week, about 5 tons of soil can be processed, which meets the AER18 feed rate need of 470 tons/week (see Section VI.B.2). The system uses conventional off-the-shelf equipment and is designed to facilitate easy cleaning and decontamination, but is totally enclosed to prevent any fugitive emissions or contamination. The facility is configured into 11 modules, each 12 feet wide by 11 feet 2 inches high by 39 feet long, with a maximum weight of about 72,000 pounds. These dimensions and weight allow transport of the modules on lowboy trailers by road throughout the U.S. Electrical power is fed through a 500-kVA transformer from a site-provided 13.8-kV line. Electrical distribution switchgear is maintained within a single module and provides for starter modules, lighting, instrumentation, and welding.

### 3. Feedstream Alignment

Clogging from melting and accumulation of soil at the core exit was experienced during the AER3/NCBC testing (see Section V.B.7). This problem was considered a result of the extremely precise alignment of the feed stream required for the very small geometry of the AER3. These problems are not experienced in the AER12. Because of much larger area in the AER12, less alignment precision is required. During the EPA/PCB trial burn performed on the AER12 in September 1983, 6.9 tons of soil were treated without problems (Reference 13). Similar results were observed during the  $\text{CCl}_4$  tests (Reference 14) and during several endurance runs



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Figure 17. Flow Schematic of an AER Commercial Pretreatment Facility.

performed by Huber. Although the soil is partially melted during treatment, the AER12 generates a much better blanket than the AER3, thus preventing contact with the reactor core wall. As the soil falls through the water-cooled PRTZ (see Figure 6), it is solidified before being collected in the solids collection vessel.

### C. COST-ESTIMATING APPROACH AND BASIS

Estimating emphasis was placed on identifying the total project remedial scope. Because the remedial action would occur on a federal reservation, certain project tasks such as permitting and delisting with EPA would be carried out by the federal government or its agent. By considering the NCBC site-specific case for the reference case cost estimate, existing conditions at the site eliminate the need for some work scope items, which might not be the case at some other contaminated site. Part of this approach is due to the conditions provided as a storage area; the other is due to facility modifications to support the previously discussed Huber and ITC technology demonstrations. These items have been listed in the assumptions for the cost estimate (Section VI.C.1).

Data sources were primarily from cost experience derived from the excavation of TCDD-contaminated soil at similar sites, with supplemental information derived from Mean's Building Construction Cost Data (Reference 23, suitably adjusted for worker productivity and other allowances as per Table 6). Caution was used in directly applying vendor quotes and literature costs.

Feasibility study cost estimates are prepared to guide a project's evaluation of alternatives and planning, from information available at the time of the estimate. The final cost will depend on actual labor and materials costs, final project scope, schedule, and other variables. As a result, the final project costs and bid prices are likely to vary from the estimates presented herein. Because of these factors, funding requirements should be carefully reviewed before using any cost estimate to establish final budgets.

## 1. Assumptions

A cost estimate depends on the assumptions and criteria used to describe the cost estimate scope. As data accumulate and project parameters are refined, the assumption and resulting estimate should be reevaluated.

General and site-specific assumptions have been made in preparing this cost estimate:

- o For this cost estimate as a reference case, the quantity of contaminated soil to be removed from the site for treatment is assumed to be 20,000 tons. Based on local soil density, the volumetric quantities are 18,800 yd<sup>3</sup>.
- o Adjustments have been made in each cost category for engineering design, services during construction, contingencies, and contractor overhead.
- o Initial capital equipment cost was assumed at \$6 million (\$4 million for the AER18 and \$2 million for the soil pretreatment facility). Capital amortization was computed based on a 5-year straight-line depreciation for study comparison with other technologies being considered by AFESC. A 7- or 10-year life may be more realistic in some cases and can vary from company to company. However, the shorter life basis will tend to show higher costs for equipment expense. A 90 percent utilization factor was also assumed in calculating the monthly use charge.
- o A lump sum of 8 percent of the total project cost is assumed for insurance and bonding charges. This item has been included in the general administration and overhead factor, which is standardized at 13 percent.

- o The final cost includes a fee of 8 percent for contractor profit based on an assumed cost plus fixed fee type of contract.
- o Personnel exposed to TCDD-contaminated soil would wear Level-C personnel protective gear, including air-purifying respirators, Tyvek<sup>®</sup> suits, butyl rubber gloves, and boot covers. Individuals working around the soil, but not directly exposed to it, would wear Level D gear. For Level D, safety shoes, coveralls, and work gloves are worn with air-purifying respirators readily available. The use of Levels C and D personnel protective gear reduces worker efficiency, shortens work periods, and includes other health and safety requirements. For Level C, these effects increase labor requirements by at least two times over standard conditions. All onsite activities require site safety officers. A decontamination trailer and a truck wash station must also be available. All workers are assumed to have entry/exit physicals, undergo a 1-week health and safety training course, and have weekly safety meetings while onsite.
- o Dust control would be required for soil handling. Dust control would be provided by water spray where closed systems are not incorporated.
- o Onsite security should be provided during all construction, excavation, stabilization, and treatment activities. An additional cost for security has not been included in this estimate, assuming that the site is located within an existing security system.
- o Site area requires no special preparation or clearing for excavation. Existing cement-stabilized soil conditions are satisfactory for truck hauling without extra treatment.

- o Well-maintained trucks and containers would be emphasized. All truck windows would be kept closed while in the excavation zone, allowing the use of Level D protection.
- o Hauling of contaminated soil will be made by equipment that remains within the contaminated area of the site; therefore, decontamination of equipment need only occur at the end of the project. Similarly, treated soil that is declared clean will be hauled to previously excavated areas, following routes outside the defined contamination zone. This approach precludes contaminating "clean" trucks, but will necessitate preplanning the grid plot excavation order and changing the visual boundary between clean and contaminated areas.
- o The treatment process area is placed within a clean area but adjacent to a contaminated area where excavated soil can be stockpiled and fed into an input chute of the soil treatment facility without requiring decontamination of equipment.
- o The cement-stabilized storage area is assumed to be sufficiently strong so that concrete floor slabs or footings are not needed to support equipment. Any supports for leveling equipment are considered to be included in the cost of equipment setup.
- o The activities for RCRA permitting and treated soil delisting with EPA and state agencies and allowance for community relations planning and presentations are considered as separate costs, covered by the responsible branch of the federal government or its agent. No allowances are made for contractor support in these activities; however, this may be a serious consideration where unusual technologies may be involved.
- o It is assumed that the delisting requirements would be specified in the permit. A test run would be performed after the AER is set up at the site and readied for operation to provide samples



for third-party verification and submittal of data to EPA for compliance with delisting requirements. It is further assumed that the results are such that the treated soil can be delisted. Subsequent treated soil monitoring for specified compounds is then considered as an in-process quality assurance procedure to release "temporary stored" treated soil for hauling to clean excavated areas. Any treated soil not meeting quality assurance (QA) requirements is returned to feedstock for reprocessing.

- o Sampling and analytical activities would be performed by qualified personnel following protocols accepted by EPA and the responsible branch of the federal government or its agent. Sampling personnel would take soil, air, and water monitoring samples as may be prescribed. The protocols would include appropriate QA to support the activities so that third-party involvement is limited to an audit function, as necessary.
- o Allowances have been made for upgrading utilities at the site, including power, water, sewer, natural gas, and telephone services, and for bringing these services to the edge of the treatment process area. These services would stay in place after the equipment is demobilized. Electrical power is assumed to be already available at the site because of earlier activities.
- o A remedial investigation that includes site survey, mapping, and preliminary data collection and analysis has been performed to further define the scope of the remedy.
- o Treatment of the contaminated soil by the AER would be the rate-limiting step for the site remedy. Other equipment is sized larger to avoid process bottlenecks, and adequate storage is provided to avoid weather or excavation delays.

- o Excavation and restoration crew rates (DOE and Davis-Bacon) are based on hiring local operating engineer personnel who can be trained for the hazardous materials aspects of the excavation work. This option was found cheaper for the reference case than bringing a trained crew from the contractor's facility and paying the appropriate labor rates and travel per diem.
- o After treatment, the original soil will be returned to the excavation site. It is expected that 15 percent of the original soil volume will be lost during treatment. Clean top soil of appropriate quality will be used to fill the remaining volume of the excavation site so that the site may be recontoured for its final intended use.
- o Sites for a parking area and warehousing are provided by the responsible federal agency.
- o A cost estimate is heavily dependent on the assumed schedule, since numerous constraints are posed by weather, permitting, and facility construction. The assumed schedule for the site remedy is shown in Table 20. Cost adjustments (particularly in capital amortization) would be necessary if the assumed schedule is significantly delayed.
- o AER soil treatment requirements for use as feedstock are a moisture less than 1 percent and a 35-mesh size.
- o By exercising careful management of the remedial action activities, the AER technology should be able to recycle nearly all dioxin-contaminated waste. Final decontamination of the AER after shutdown may be an exception. Because of this general expectation, no costs have been identified. However, should there be hazardous wastes at the end of the remedial action that the AER cannot recycle, it is assumed that an RCRA-permitted

TABLE 20. ASSUMED SCHEDULE FOR RESTORATION REFERENCE CASE<sup>a</sup>

<u>Schedule Element</u>	<u>Duration (weeks)</u>
Preparatory Work Period	
AER long lead procurement; equipment fabrication/troubleshooting is the critical path for first field use. <sup>b</sup>	36
Equipment Use Period	
Transport from Borger, Texas, and unloading at site	1
Equipment erection	4 <sup>c</sup>
Equipment testing and debugging	5 <sup>c,d</sup>
Detoxification of 20,000 tons of soil	46
Decontamination and disassembly of equipment	4
Load and transport of equipment to Borger	<u>2</u>
Total Equipment Use Period	62 weeks

a. Schedule applies following contract award.

b. Within this schedule envelope, other activities such as site permitting and delisting with EPA and site preparation work occur. This presumes that permitting is with EPA Region IV, as would apply for the NCBC location. However, for some regional offices, the permitting process may take as long as 2 years.

c. Pretreatment and AER modules would be initially assembled and debugged after construction at Borger. The first field erection and debugging are estimated at 9 weeks. Subsequent projects are expected to require less time as crews become fully trained.

d. This duration includes conducting the test burn and sampling for delisting compliance testing. The third-party analysis and data validation would involve about 6 weeks. During this period, AER soil detoxification would occur; however, treated soil would be stored in enclosed steel boxes until authority is received to release the soil according to the restoration plan.

disposal facility will exist so that this waste can be shipped offsite for disposal. If this condition does not exist, a permit for interim storage of hazardous wastes onsite will be required, which is not included as a cost.

## 2. Cost Categories

Costs are separated into four categories to help identify the fixed and operating costs that are the responsibility of Huber and of DOD (or its agent). This assumed cost split approximately duplicates the cost sharing that occurred during the recent onsite AER/NCBC pilot-plant test. Huber would be responsible for the fixed and operating costs within the treatment process area, and DOD (or its agent) would be responsible for the remainder of the costs. Any adjustment of this cost split would change the division of responsibility but would not appreciably affect total site cost. The four categories recommended and their major elements are described below.

### a. Cost Category 1, Common Remedial Costs

This category includes the costs for all common site preparation and removal work required to support the AER (or any other) soil treatment process. Also included are all utility connections (water, sewer, telephone, gas, fire protection) exclusive of the area inside the treatment process area.

Ancillary facilities are needed for any treatment process and would be located outside the treatment process area. These include office and breakroom trailers, decontamination facilities, and a 50-gpm water treatment facility consisting of a four-stage process train of sand filtration, 5-micron cartridge filters, activated carbon, and 5-micron post filters.

The 20,000 tons of contaminated soil would be excavated by a 9-man crew with smooth-bucket backhoes and dozers or a tractor with a hoe ram attachment, and placed into 15-ton (net) enclosed steel boxes mounted

on Galbraith-type totally enclosed steel rolloff trucks. Four loads/day, with a maximum net soil quantity of 68 tons, will be loaded over a 5-hour period at the excavation area to meet the average daily requirement of soil to be treated by the AER. The trucks would transport the loaded boxes to a storage next to the input hopper to the soil pretreatment facility. A dump truck outside the contamination zone would transport the released clean soil to clean excavation sites. The excavation crew would also map excavation progress, lay out road routes, and change the boundary between contaminated and clean areas as needed.

The decontamination station would consist of a below grade rectangular sump covered with heavy grating and surrounded by splash walls and a roof or some similar swimming pool type of structure. The station would be supplied with water, power, and phone connections and would pump the spent washwater into a pressurized sewer connecting to the water treatment facility. This station will be used to decontaminate trucks and equipment, as needed.

As mentioned, the average rate of excavation would correspond to the average daily throughput at the soil treatment facility. A soil volume equivalent to 7 days, 470 tons of operation at the NCBC site treatment facility would be held on reserve at the site for periods of inclement weather or other delays in excavation. The excavation equipment can operate at a maximum rate that is twice the AER treatment rate, to enable the soil inventory to catch up after a period of depletion.

Significant volumes of dissimilar material could complicate the soil storage and material preparation. Small-to-moderate volumes of dissimilar material such as large rocks, debris, or contaminated construction material (geotextile, piping, liners, etc.) could be handled in several ways. For instance, the dissimilar material could be placed in separate steel boxes and kept at the 7-day storage area until processing. It may also be feasible to stockpile the debris in a designated area next to the soil pretreatment facility and to use a front-end loader to sort or mix the waste before the material preparation process. To the extent practical, isolating the dissimilar material in place may be advantageous,

especially if a large volume exists. Leaving the material in the excavation zone would require a durable cover to minimize exposure and prevent contaminant runoff. Selecting a method of handling the dissimilar material is a site-specific decision based on the type of material, location, and relative volume. For this study, it has been assumed that there is a minimal amount of dissimilar material and that a small enclosed stockpile at the pretreatment facility will be sufficient.

The contaminated area would be divided into workable zones separated by haul routes. The zones would be sequentially excavated, in thin layers (2 to 6 inches), and then refilled with the treated soil, once the soil analyses for a particular zone pass quality assurance requirements.

Once the site has been cleaned of contaminated soil, final restoration would consist of grading the spread treated soil and then covering this area with clean top soil and fill since approximately 15 percent of the original soil mass is lost in processing (see Section IV.C.2). The area would be graded and planted with indigenous grasses. The steel rolloff boxes used for daily operations, raw storage, and temporary ash holding will be decontaminated and salvaged.

Because of the unique training and experience required, the health and safety personnel are assumed to be contracted from outside the local area. Per diem and miscellaneous expenses are computed at 25 percent of the total (burdened) labor cost.

b. Cost Category 2, Common Operating and Monitoring Costs

During the operation of the AER (or any other) treatment process, substantial monitoring and ancillary site costs are necessary to certify the treatment efficiency and to ensure permit and treated soil delisting compliance. An onsite coordinator has been included in the cost estimate to act as representative for necessary day-to-day decisions and to oversee the monitoring and water treatment programs.

A sampling plan would be prepared to guide the site excavation. Given the cleanup level, desired statistical accuracy, confidence limits, and detection levels, the necessary sample spacing, compositing, and QA/QC protocol would be developed. At this time, it is assumed that three samples would be analyzed for every 2500 ft<sup>2</sup> of surface excavated. Additional samples would be taken from the soil at the bottom of the excavations to ensure untouched soil has constituent concentrations that are less than the EPA criteria for declaring the site nonhazardous. A 1 ppb cleanup target has been assumed for this estimate, although the report by the Centers for Disease Control (Reference 10) provides a rationale for establishing less stringent cleanup targets in commercial use areas (see discussion in Section I.B.1).

The monitoring program would also include sampling and analysis of site ambient air and waste streams exiting the AER process. A network of four perimeter high-volume air samplers would be installed to collect background data and monitor offsite emissions during excavation, operation of the soil pretreatment facility, and operation of the AER. At the AER and soil pretreatment facilities, monitoring of the waste streams from the process would occur at various compliance points. AER process sampling of the treated soil should be sufficient monitoring because use of a baghouse filter and activated carbon filters in the gas effluent stream precludes the need to monitor stack gases. Soil pretreatment plant scrubber wastewater could require sampling.

A mobile onsite laboratory would be set up and operated to minimize analytical costs and improve sample turnaround time to 72 hours or less. The onsite lab would be equipped with a high-resolution gas chromatography/mass spectrometer (GC/MS) and ancillary equipment. A six-man crew, including four analytical chemists and two sampling technicians, would be needed to oversee the ambient air and process monitoring programs. Operation of this group would be primarily day shift, with limited capability to collect samples and move ambient monitoring equipment, as needed, during back shifts, weekends, and holidays. Necessary QA checks would be performed by this crew. Because of the unique training and experience required, these personnel are assumed to be

contracted from outside the local area. Per diem and miscellaneous expenses are computed at 25 percent of the total (burdened) labor cost.

Additional common operating and monitoring costs will include user charges for the water, power, and gas provided to the site ancillary buildings and yard facilities outside the soil treatment process area. This cost category also includes the operation of the 50 gpm water treatment facility. Sources of wastewater that have potential for contamination include accumulated excavation site runoff, personnel and equipment decontamination facilities, soil storage runoff, scrubber and cooling water blowdown, and miscellaneous wash-down sources.

c. Cost Category 3, AER Setup Costs

Huber would be responsible for the mobilization and demobilization of the soil pretreatment facility and the AER within the treatment process area. These units would be constructed in prefabricated modules, each 12 feet wide, 11 feet high by 39 feet long, with a maximum weight of 72,000 pounds. They would be preassembled and tested at Borger, Texas. The modules would be shipped in 27 truckloads to the site, where they will be erected and retested over a 9-week period. After onsite operation, the units would be decontaminated, disassembled, and shipped to the next site.

The pretreatment facility would receive the loaded bins, and then dry and crush the material to a uniform 35-mesh size (see Appendix X for details). The AER would receive the material and detoxify it at 3600 to 4100 °F via radiant heat in a nitrogen-filled reactor core. The residue would pass through two postreactor cooling zones and would then be conveyed to one of six product-storage tanks. Here the material would be held for 48 to 72 hours to allow time for laboratory testing of the residue. The soil pretreatment and AER modules have overall dimensions, given in feet, of 45 long x 40 wide x 65 high and 75 long x 35 wide x 80 high, respectively.



d. Cost Category 4, AER Facility Operating and Maintenance Costs

During operation of the AER, Huber would be responsible for all operating and maintenance costs within the treatment process area, including labor, utilities, maintenance materials, and equipment amortization.

An operating crew of 21 would be provided to enable round-the-clock operation. The crew includes: manager, clerk, maintenance personnel, reactor operator, yard operator, pretreatment operator, relief operator, and engineer/safety personnel. Most of the personnel would be grouped into four shift crews to maintain three 8-hour shifts/day and would have one relief crew. This operating crew is similar to or less than that required for operating other soil treatment processes. For example, the EPA mobile incinerator had a crew three times larger when conducting the Denney Farms trial burns. It is not known what its comparable crew size would be for extended site operations.

Labor costs are computed at the rate of 2.13 times the raw salary. Per diem and miscellaneous expenses are computed at 25 percent of the total (burdened) labor cost. The crew would be onsite for 6 weeks of equipment testing, plus 46 weeks of full-rate operation, for a 12-month total pay period to treat 20,000 tons of soil.

The major utility and fuel requirements necessary for the operation of the AER facility include power, water, nitrogen, and natural gas. Electricity consumption is based on 1100 kWh/ton of reactor throughput, plus 200 kWh/hour of operation for ancillary equipment. Nitrogen at a rate of 200 sft<sup>3</sup>/min is used as a blanket gas in the reactor core. Lastly, at the soil pretreatment facility, the indirect dryer requires natural gas at a rate of 3000 ft<sup>3</sup>/hour.

An allowance of 3 percent of the capital equipment cost/year has been included for general maintenance materials. Labor costs for maintenance personnel are included in the 21-man operating crew. Other

maintenance expenses consist of replacement costs for the core, electrodes, filter baghouse, and carbon absorbents.

Based on the earlier stated assumption, the capital equipment monthly use charge was calculated to be \$111,000. From the schedule in Table 20, project use of the equipment is over 14.5 months, although the actual treatment of 20,000 tons of soil occurs during only 10.5 months. The remaining 4 months are taken by equipment shipping both ways, setup, testing, decontamination, and disassembly.

#### D. COST ESTIMATE

The estimate for the reference case is summarized in Table 21. A detailed breakdown is presented in Appendix Y, Exhibit 1. This estimate encompasses a comprehensive scope of excavation, transportation, soil preparation, and AER treatment costs (direct, indirect, and contractor fee costs) for 20,000 tons of soil. Estimated total cost is \$14.3 million, or approximately \$716/ton ( $\$762/\text{yd}^3$ ). Changes in the description, soil volume, site conditions, work scope, facility siting, criteria, or contingencies would correspondingly affect the estimated costs. Without careful consideration of these fundamental cost determinants, these estimates should not be inferred to be representative for any other site, nor should estimates prepared on a different basis by other parties be considered equivalent.

#### E. SENSITIVITY ANALYSIS

A sensitivity analysis was conducted on six key variables (geographic location, soil quantity, electric power, labor rates, capital costs, and transportation) to help assess the effect of specific assumptions on overall cost. Key variables were doubled, and then halved to identify their effect on the overall remedial cost. Most costs (except electric power) were fully burdened, i.e., with the appropriate engineering, administrative, and contingency adjustments. Since the electrical power cost is an expense paid directly to the utility, with negligible administrative expense or contingency, the full burdening of electrical

TABLE 21. SUMMARY OF SITE REMEDIAL COSTS FOR AER TREATMENT OF  
20,000 TONS OF SOIL AT NCBC SITE (REFERENCE CASE)

	a Cost (\$1000)	b Cost Per Ton (\$)	Cost Per c Cu Yd (\$)	Percent
COMMON REMEDIAL COSTS				
Mobilization	435	21.8	23.1	3.0
Construction	842	42.1	44.8	5.9
Excavation, material handling, and site restoration	1,769	88.4	94.1	12.4
	<u>3,046</u>	<u>152.3</u>	<u>162.0</u>	<u>21.3</u>
COMMON OPERATING AND MONITORING COSTS				
General	121	6.1	6.4	0.8
Monitoring and analysis	1,616	80.8	86.0	11.3
Facility operations	293	14.6	15.6	2.0
	<u>2,030</u>	<u>101.5</u>	<u>108.0</u>	<u>14.1</u>
AER SETUP COSTS				
Transportation to and from site	247	12.4	13.1	1.7
Setup and shakedown	209	10.4	11.1	1.5
Removal	148	7.4	7.9	1.0
	<u>604</u>	<u>30.2</u>	<u>32.1</u>	<u>4.2</u>
AER FACILITY OPERATING AND MAINTENANCE COSTS				
Equipment use charge	2,358	117.9	125.4	16.5
Utilities	2,394	119.7	127.4	16.7
Labor	2,232	111.6	118.7	15.6
Other operating costs	1,664	83.2	88.5	11.6
	<u>8,648</u>	<u>432.4</u>	<u>460.0</u>	<u>60.4</u>
Total Cost	\$14,328	716.4	\$762.1	100.0%

a. These costs in 1986 dollars include engineering, insurance and bonding, administrative, contingency and contractor fee adjustments. Refer to Appendix Y, Exhibit 1, for the applied cost burdens.

b. Cost per ton based on 20,000 tons.

c. Cost per cubic yard based on 18,800 yd<sup>3</sup>.

power costs would have inappropriately stated the cost sensitivity of, for example, doubling the power costs.

Results of this analysis are shown in Table 22 and can be used to identify "best case" and "worst case" scenarios, and help adjust contingencies or reserve funds accordingly. The first two variables, location and soil quantity, are the two primary underlying assumptions that, in turn, determine a large number of other assumptions and parameters. The other four variables (electrical power rates, labor, capital, and transportation) are variants in consumption and/or unit costs, which have a lesser impact on remedial cost. Other lesser variables, and an imponderable number of combinations, could have a measurable impact on costs, but they are beyond the scope of this study, and would need to be considered on a site-by-site basis.

#### 1. Location

The assumed NCBC site location and site conditions described earlier are nearly ideal for optimizing the operation of a treatment facility. The nonfreezing, mild climate allows year-round soil excavation with a minimal amount of inventory storage. The flat site, cement, and stabilized soil make for the routine equipment setup and roadway layout. These factors are favorable to economical field work and year-round operation.

On the other hand, a more difficult site located in a northern climate would incur added costs and possible winter shutdowns. For example, at a generic site in the midwestern United States, there can be up to 6 winter months when the soil is so wet or frozen that soil excavation and handling are impractical. Two basic weather-induced options are part of this scenario:

- o Construct a 6-month heated, 11,200 ton, (10,600 yd<sup>3</sup>) enclosed wastepile that can be accessed by equipment. This would enable year-round operation, but at an added

TABLE 22. SUMMARY OF SENSITIVITY ANALYSIS

	Cost Categories \$/ton				Resultant Total <sup>a</sup>	
	Common Remedial	Common O&M	AER Site Setup	AER Facility O&M	\$/ton	\$ (x1000)
<u>Reference Case Costs</u>	152.3	101.5	30.2	432.4	716.4	14,328
<u>Location</u> (weather impact only)						
Enclosed Wastepile	+131.0	--	--	--	847.4	16,947
Winter Shutdown (6 mo)	--	--	--	+64.5	780.9	15,618
<u>Quantity</u>						
Double to 40,000 tons (37,600 yd <sup>3</sup> )	-48.2	-18.4	-15.1	-27.3	607.4	24,295
Halve to 10,000 tons (9,400 yd <sup>3</sup> )	+99.2	+42.7	+30.2	+40.6	929.1	9,291
<u>Electrical Power Cost</u> (w/o cost burdens)						
Double	--	+1.9	--	+56.6	724.9	15,498
Halve	--	-1.0	--	-28.3	687.1	13,743
<u>AER Facility Labor Cost<sup>b</sup></u>						
Double	--	--	--	+111.6	828.0	16,560
Halve	--	--	--	-55.8	660.6	13,212
<u>AER Equipment Use Charge<sup>c</sup></u>						
Double	--	--	--	+117.9	834.3	16,686
Halve	--	--	--	-58.8	657.5	13,149
<u>AER Transportation Cost</u>						
Double	--	--	--	+12.4	728.8	14,575
Halve	--	--	--	-6.2	710.2	14,204

a. These costs, in 1986 dollars, with the exception of power cost, include engineering, bonding and insurance, administrative, contingency and contractor fee adjustments. Refer to Appendix Y, Exhibit 1 for the applied cost burdens.

cost of \$2.62 million, or \$131/ton (\$139/yd<sup>3</sup>, an 18 percent increase). A cost summary is presented in Table 23. Appendix Y, Exhibit 2, describes these added costs in detail.

- o Shut down the facility during winter months at an added cost of \$1.29 million, or \$64.5/ton (\$68.6/yd<sup>3</sup>), a 9 percent increase. A cost summary is presented in Table 24. Appendix Y, Exhibit 3, describes these added costs in detail. These costs primarily result from the increased equipment use charge/rental period and the five-man standby crew for 6 months.

The second option was selected as the least costly method of dealing with severe winter weather. Most U.S. sites have less than 6 winter months, and would correspondingly incur smaller added costs. Other site variables such as soil type and topography are too site-specific to forecast their possible cost impact in this study.

## 2. Quantity

Soil quantity will likely be the most important variable, because it directly impacts cost and schedule in nearly every cost category. Furthermore, preexcavation estimates of soil volumes are often accurate only to within  $\pm 100$  percent. Therefore, project planning and budgeting need to consider the accuracy of the soil volume estimate and the corresponding cost sensitivity. The reference site estimate assumes that 20,000 tons (18,800 yd<sup>3</sup>) are processed in a total of 11 months. In addition, there are substantial fixed time and cost requirements to set up and dismantle the AER and all of the ancillary equipment. Therefore, substantial economies of scale are associated with processing larger volumes of soil. As Table 22 indicates, doubling the soil volume to 40,000 tons (37,600 yd<sup>3</sup>) reduces the total remedial unit cost by \$109/ton (\$116/yd<sup>3</sup>, a 15 percent decrease) to \$607/ton (\$646/yd<sup>3</sup>). Similarly, a reduction to about 10,000 tons (9400 yd<sup>3</sup>) increases the unit cost by \$213/ton (\$226/yd<sup>3</sup>, a 30 percent increase) to \$929/ton (\$988/yd<sup>3</sup>). Table 25 presents a summary comparison of the four general cost categories

TABLE 23. SUMMARY OF COSTS FOR 11,200 TON INTERIM SOIL STORAGE FACILITY FOR NORTHERN CLIMATE

<u>Common Remedial Cost Category<sup>a</sup></u>	<u>Cost (\$1000)</u>
General	91.0
Site preparation	24.5
Containment base	219.0
Containment sidewalls	58.0
Containment enclosure	574.0
Building cleaning and restoration	588.0
Operation and maintenance	118.0
Construction subtotal	\$1,672.5
Contingencies (25%)	481.1
General administration (13%)	271.8
Contractor fee (8%)	194.0
Total estimated cost	\$2,619.3

a. See Appendix Y, Exhibit 2, for detailed breakdown of the category estimate.

for these two cases with the reference site case. Detailed cost breakdown estimates are shown in Appendix Y, Exhibits 4 and 5, for the 40,000 ton (37,600 yd<sup>3</sup>) and 10,000 ton (9400 yd<sup>3</sup>) volumes, respectively.

Because the labor cost is a substantial portion of the AER operating cost (see Table 22), an increased feed rate would shorten the duration to complete the treatment. The AER labor cost would reduce because the same crew size would likely be sufficient for only a slightly larger unit. However, there would be an increase in the equipment monthly use charge, but this may be offset by reduction of time being charged. Depending on excess capacity of other labor, rented equipment, and leased facilities supporting the project, additional cost savings may be possible as well. A rough cost estimate of potential cost savings was performed for a feed rate of 4 tons/hour, which is a rate comparable to kiln-type units. This rate is an increase of 143 percent over the rate used for the AER18.

TABLE 24. SUMMARY OF COSTS FOR IDLE AER SITE OPERATIONS FOR 6 MONTHS IN NORTHERN CLIMATE

<u>AER Facility Operating and Maintenance Cost Category</u>	<u>Cost<sup>a</sup></u> <u>(\$1000)</u>
<u>General</u>	
Second startup and shakedown	15
AER equipment and facility decontamination	10
Equipment use charge (6 months)	666
<u>Standby O&amp;M Costs</u>	
Labor at AER facility	166
Rental equipment remaining on site	18
Utilities	<u>6</u>
<u>O&amp;M Cost Subtotal</u>	\$881
Contingencies (20%)	176
General administration (13%)	137
Contractor fee (8%)	<u>96</u>
Total estimated cost during 6-month idle operations	\$1,290

a. See Appendix Y, Exhibit 3, for detailed breakdown of the category estimate.

The soil treatment production would be reduced 3.3 months. Because the reference case cost estimate (Appendix Y, Exhibit 1) used a 12 month base, a general savings factor is 0.28 for time-based items. Assuming there would be no need to increase the number of personnel, pay overtime, or obtain larger capacity rented/based equipment and facilities and the



equipment use charge by the ton is constant, the following potential productivity savings, including burdens and fee, were estimated:

<u>Category</u>	<u>Savings (\$1000)</u>
Common remedial	386
Common Operating and Monitoring	469
AER setup	0
AER facility Operating and Maintenance	625
Total	1,480

Because insufficient data are available to support these assumptions, this cost savings is speculative. Cost estimating for a given process often is based on cost/yd of material, which would negate the feed rate as a variable. For the AER concept, the same crew size could operate the unit. A better estimate of the overall cost savings may be determined by a more detailed analysis.

### 3. Power Cost

The total direct power cost (without burdens) for the base case is \$1.17 million (\$59/ton, \$62/yd<sup>3</sup>) or about 8 percent of the \$716/ton (\$762/yd<sup>3</sup>) total remedial cost. The AER uses 90 percent of the total power consumption. Doubling the power cost, because of either increased consumption or unit prices, would increase the unit cost by \$59/ton (\$62/yd<sup>3</sup>, an 8 percent increase) to a total of \$774/ton (\$824/yd<sup>3</sup>). Similarly, a 50 percent reduction would decrease the unit cost by \$29/ton (\$31/yd<sup>3</sup>, a 4 percent decrease) to \$687/ton (\$731/yd<sup>3</sup>).

### 4. Labor Cost

The total labor cost for AER soil treatment is equivalent to \$112/ton (\$119/yd<sup>3</sup>) for a staff of 21 spread over all work shifts. There is also an additional onsite staff of 25 for excavation, monitoring, and coordination tasks, as well as a peak construction crew of over 50. Doubling the AER labor cost would cause an increase of \$112/ton (\$119/yd<sup>3</sup>, a 16 percent increase) to \$828/ton (\$881/yd<sup>3</sup>). Similarly, a

50 percent reduction in AER labor costs would result in a \$56/ton (\$59/yd<sup>3</sup>, an 8 percent decrease) to \$661/ton (\$703/yd<sup>3</sup>).

#### 5. Equipment Use Charge

At a monthly rate of \$111,000 for 14.5 months related to the NCBC project, the burdened total equipment charge for the reference case was calculated to be \$2,358,000 or \$117.9/ton (\$125.4/yd<sup>3</sup>). Doubling the use charge rate would add 16 percent to the unit cost at \$834.3/ton (\$887.5/yd<sup>3</sup>). A 50 percent reduction in the equipment use charge would result in a \$6.2/ton (6.5/yd<sup>2</sup>, an 8 percent decrease) reduction of the unit cost to \$710/ton (\$119/yd<sup>3</sup>).

#### 6. Transportation Cost

Transportation of the soil pretreatment and AER modules to and from Borger to Gulfport, Mississippi, constitutes \$12.4/ton or 1.7 percent of the total unit cost. Doubling the roundtrip distance from 1300 to 2600 miles would add \$12.4/ton (\$13.1/yd<sup>3</sup>, a 1.7 percent increase) of the total remedial unit cost. Reducing the transportation cost by 50 percent [\$6.2/ton (\$6.5/yd<sup>3</sup>, a 0.9 percent decrease)] would have a negligible effect on the total unit cost.

#### 7. Other Variables

Other assumptions could have a major bearing on site remedial costs, but are so site-specific that quantifying their sensitivity is not possible at this time. Some that may be candidates for a future site-specific sensitivity analysis include:

- o Rolloff Box Decontamination: A crane could be used to transfer the soil boxes across the hot line and through decontamination. The crane and two additional trucks would be needed for this decontamination method, but it would result in faster excavation rates.

TABLE 25. SUMMARY OF COSTS FOR INCREASED/DECREASED TREATED SOIL VOLUME COMPARED TO REFERENCE CASE

Cost Category	Reference Case	200% Case <sup>b</sup>		50% Case <sup>c</sup>	
	Cost (\$1000) <sup>a</sup>	Cost (\$1000)	% Change <sup>d</sup>	Cost (\$1000)	% Change <sup>d</sup>
1. Common remedial	3,046	4,167	+36.8	2,515	-17.4
2. Common operating and monitoring	2,030	3,322	+63.7	1,442	-29.0
3. AER setup	604	604	0	604	0
4. AER facility operating and maintenance	8,648	16,202	+87.4	4,730	-45.3
Total	14,328	24,295	+69.6	9,291	-35.1

a. See Table 21 for subtotals of reference case.

b. See Appendix Y, Exhibit 4 for category detail breakdown.

c. See Appendix Y, Exhibit 5 for category detail breakdown.

d. Percent change relates to reference case.

- o Box vs. Bag vs. Bulk Storage: Enclosed steel boxes were selected for this estimate because of their cost, flexibility, and inventory control for short-term small soil inventories. Polyethylene bags and pole barns have been used for long-term soil storage, but are too labor-intensive to use for large soil volumes. Bulk soil storage has historically been used for long-term soil storage, but would involve soil rehandling/testing, and the construction of a double-lined enclosed storage facility.
- o Cleanup Criteria: The 1-ppb TCDD level has been applied at residential sites, but may be adjusted to less stringent levels for other exposure scenarios, while still maintaining the same risk target (see Section I.B.1). Since the majority of soils at most sites are slightly above the 1-ppb level, a modification in cleanup criteria will have a substantial impact on overall soil volume and remedial cost.
- o Runoff Treatment: The NCBC site has dikes to prevent runoff based on 10-year flood plain data. If a generic site is flat and has high permeability soils, a runoff collection system is not needed.
- o Personnel Protection: The current EPA health and safety protocol requires the use of Level C personnel protection to prevent direct exposure to TCDD-contaminated soil. Buildings and enclosed equipment can usually be provided with suitable filtration devices to protect workers wearing Level D equipment. As shown in Table 26, the level of personal protection can have a substantial impact on remedial cost. An increase in the number of workers wearing Level C protection or changing to Level B can substantially affect the remedial cost.

- o Delisting: The fused character of AER-treated soil should significantly improve the likeliness of its delisting, relative to other treatment processes. Because of the analyzed low concentrations for those constituents listed in 40 CFR 261.24 and assessment of Federal Register, Vol 51, No. 216, dated November 7, 1986, the treated NCBC soils would not be expected to encounter difficulty in the delisting process if the Huber process were selected for full-scale remedial action (see Section V.B.5). However, other potential sites with high concentrations of the listed inorganics could be a concern. The possible surface enrichment of treated soil particles by volatilized inorganics has not been determined. Depending on the organic concentrations, significant surface enrichment could adversely impact EP toxicity test results. The presence of inorganics should be assessed before any remedial action is undertaken.

## F. EVALUATION

### 1. Cost Estimate Validation

The cost estimate for cleanup of NCBC has been reviewed by the cost estimating group at EG&G Idaho. Details of the report are presented in Appendix Z. After several comments were resolved, the resubmitted costs associated with the AER soil treatment processes (cost categories 3 and 4) were reviewed as reasonable and consistent, based on historical data. This cost estimate is presented in this report. The cost estimates for the common remedial and common operating and monitoring costs (cost categories 1 and 2) were initially developed by CH<sub>2</sub>M Hill for a generic site in Mississippi. During the review process, AFESC and EG&G Idaho project personnel decided that an NCBC site-specific basis would be more appropriate. Revision for this change in scope was accomplished by the EG&G Idaho cost estimating personnel. Numerous changes were discussed with the CH<sub>2</sub>M Hill estimator and agreement was reached. The revised cost

TABLE 26. REMEDIAL COSTS RELATIVE TO CONVENTIONAL CONSTRUCTION

Factor <sup>a</sup>	Level of Protection					
	B		C		D	
1. <u>Crew Size</u>						
Productive crew size	10		10		10	
Support team	3		2		1	
Total team size	13		12		11	
Ratio of: $\frac{\text{crew size}}{\text{total team}}$		0.77		0.83		0.91
2. <u>Available Work Time</u> (as percent of paid time)						
Moderately cool (65°F)	320 min	0.71	370 min	0.82	420 min	0.93
Moderately hot (85°F)	220 min	0.49	270 min	0.62	380 min	0.85
3. <u>Gross Productivity</u>						
Light work		0.8		0.90		1.0
Heavy work		0.6		0.75		0.9
4. <u>Net Remedial Productivity =</u> <u>Conventional Productivity</u>	0.46 to	0.24	0.61 to	0.37	0.85 to	0.70
5. <u>Remedial Site Labor =</u> <u>Conventional Labor</u>	2.2 to	4.2x	1.6 to	2.7x	1.2 to	1.4x
6. <u>Cost Impact Multiplier</u> (over conventional costs)	65°F	85°F	65°F	85°F	65°F	85°F
for items with 40% labor	1.48	2.28	1.24	1.68	1.08	1.16
for items with 50% labor	1.6	2.6	1.30	1.85	1.10	1.20
for items with 60% labor	1.72	3.12	1.36	2.02	1.12	1.24
<u>PROTECTIVE EQUIPMENT COST</u>						
Purchase	\$52		\$30		\$10	
Disposal	18		18		6	
Monitoring equipment	10		7		7	
Total (\$/d/person)	\$80		\$55		\$23	

a. See General Notes, next page.

TABLE 26. REMEDIAL COSTS RELATIVE TO CONVENTIONAL CONSTRUCTION (CONCLUDED)

GENERAL NOTES TO TABLE 26

1. Based on a 10-man working crew, paid for 8 hours/day, with a support team of 1 to 4 people (depending on protective level).
2. Of a total of 480 paid minutes/day, a portion of each team member's time is spent on suit-up/off, breaks, changing air tanks, and site safety meeting. The following daily time breakdown was assumed:

	<u>B</u>	<u>C</u>	<u>D</u>
Safety meetings	20	10	10
Suit-up/off	60	40	10
Air tank change	20	0	0
Breaks	40-140	40-140	30-70
Cleanup	20	20	10
Net available time			
Moderately cool	320	370	420
Moderately hot	220	270	380

3. Gross productivity ratio is the efficiency for work actually done during a worker's available work time.
4. The ratio of net remedial to conventional productivity is the product of multiplying each of the above adjustments.
5. The ratio of remedial labor to conventional labor indicates the additional labor required to complete a task in protective equipment.
6. The Cost Impact Multiplier for the additional remedial labor (caused by the above productivity losses) results in an 8 to 540 percent cost increase over conventional construction costs, depending on the protective level and the labor/material split for a given cost element. Most conventional cost elements have between a 40- and 60-percent labor component.

estimates are presented in this report. The assumptions list presented in Section VI.C.1 were expanded to reflect the revised scope.

The cost estimate review methodology was largely based on a reasonable sequence of operations at the NCBC HO storage site and knowledge of earlier AER operation. The costs were reviewed or estimated (in the revision of cost categories 1 and 2) using a variety of cost estimating tools, specifically, the R.S. Means Manual (Reference 24), the Richardson Estimating Standards (Reference 25), as well as the estimator's experience. These tools are based on historical costs associated with work units and have proven to be credible over time through many completed projects. The estimating accuracy obtained using the estimating technique is strictly dependent upon the viability of the assumptions used for the defined work scope. Based upon the work scope provided and the stated assumptions, the estimate presented for the remedial action at the NCBC HO storage site is within an accuracy of  $\pm 25$  percent of the cost.

## 2. Summary

The most complete, up-to-date information possible was used to prepare this cost estimate for the reference case excavation, transportation, soil preparation, and detoxification of 20,000 tons (18,800 yd<sup>3</sup>) of TCDD-contaminated soil at NCBC HO-contaminated site located in Gulfport, Mississippi.

Given the limited amount of site data currently available, this cost estimate provides a complete description of all necessary direct and indirect costs associated with the proposed site remedy, including allowances for worker productivity losses, health and safety, engineering, administration, contingencies, contractor fee, etc. These costs are segregated into four cost categories (common remedial, common operating and monitoring, AER setup, and AER facility operating and maintenance) to identify the fixed and variable cost elements associated with the AER (or any other) treatment process, and those associated with the necessary ancillary site work, as summarized in Table 21. To be comparable, any



other remedial alternative must be estimated in the same manner and be done for a similar scope.

For the reference case remedial action, the estimated cost is \$14.3 million (1986 dollars). This cost is equivalent to \$716/ton ( $\$762/\text{yd}^3$ ) of restored soil. The most significant cost of the four cost categories pertained to AER facility operating and maintenance costs (category 4) at \$8.6 million or 60.4 percent of the estimated cost. Next significant was the common remedial cost (category 1) at \$3.0 million or 21.3 percent of the estimated cost. This figure was substantially reduced from the initial estimate by being NCBC site-specific rather than generic. Also, federal agency costs associated with permitting, delisting, and community relations planning are not included. A rough cost estimate indicates a potential cost savings of about \$1.5 million if the AER soil feed rate were increased to 4 tons/hour; however, a more detailed analysis is recommended.

The sensitivity analysis showed that the quantity of soil to be treated was the most significant variable. Doubling the quantity to 40,000 tons ( $37,600 \text{ yd}^3$ ) reduced the unit cost by \$109/ton ( $\$116/\text{yd}^3$ ) or 15 percent to \$607/ton ( $\$646/\text{yd}^3$ ). Halving the quantity to 10,000 tons ( $9400 \text{ yd}^3$ ) increased the unit cost by \$213/ton ( $\$226/\text{yd}^3$ ) or 30 percent to \$929/ton ( $\$988/\text{yd}^3$ ). AER facility labor cost was the next most sensitive variable, followed by equipment use charge and electrical power variables. As previously discussed, cost/ton can be reduced by decreasing labor costs through an increased feed rate; however, this may require some redesign of the process equipment to achieve an optimized condition. For the two location options considering the effect of winter impacts on excavation, a shutdown of operations was found significantly superior to constructing an enclosed wastepile. The AER transportation cost variable was relatively insignificant for a contiguous United States use. However, the modular compactness of the AER process could be beneficial for transporting and setting up at remote sites, compared to other more bulky, extensive assembled systems such as kilns and their associated air purification equipment.

## SECTION VII

### CONCLUSIONS AND RECOMMENDATIONS

#### A. CONCLUSIONS

##### 1. AER Demonstration Test

The J. M. Huber Corporation performed a field demonstration of the AER process with dioxin-contaminated soil at NCBC in Gulfport, Mississippi, by using its AER3 mobile pilot plant. A total of 1100 pounds of soil were processed. This demonstration was accomplished in June 1985 within the agreed budget and schedule. Problems were encountered in the field, but were resolved without adversely impacting the operation. The most serious problem was related to soil clogging at the core exit. Sensitivity of the small-sized AER3 to misalignment of the feedstream and maximizing of the feedstock rate were attributed as causes, which can be controlled in large-scale operation of an AER.

Based on Battelle analytical results, the AER3 demonstrated destruction of total dioxins and furans to a concentration in the treated soil of less than 1 ppb, which was a primary test objective. Results from the NCBC test-treated soil sample analyzed by Battelle showed none of the total dioxins and furans as detectable. Sum of the DLVs for the six total isomer classes was 0.12 ppb. The 2,3,7,8-TCDD specific DLV was 0.04 ppb. CAL total isomer class data were questioned because the standards could not be verified with EPA-provided standards. However, data for the split of the NCBC test-treated soil sample showed the sum of the indication or DLV for each of the six isomer classes to be 0.35 ppb, which also satisfied the criteria. CAL data for the 2,3,7,8-TCDD specific analysis could not be validated because CAL did not fully follow the EPA CLP protocol. The Battelle results are the more valid from both analytical laboratories. However, general conclusions based on the Battelle data must take into account that only a very limited number of samples (3) from both Huber and ITC technology tests were analyzed.

Semivolatile organic compounds 2,3,5/2,4,6-trichlorophenol and 2,4-dichlorophenol, which were present in the soil feedstock (ranging from 10 to 310 ppm) were effectively destroyed in the treated soil. No organic compounds were detected in the samples of treated soil. Only di-n-butyl phthalate was detected in a treated soil sample (from the development runs) at a concentration over 1 ppm, and this was only 1.2 ppm. These results should be used as a guide. CAL semivolatile organic compound analysis could not be validated because of excessive time between receipt of the samples and extraction and analysis of the samples. This delay was even more serious regarding CAL's analysis for volatile organic compounds, organochlorine pesticides, and PCBs; these analytical data also could not be validated.

Inorganic concentrations in the treated soil were sufficiently low that an EP toxicity test was not needed. Zinc and lead were the dominant inorganics; however, compared to the feedstock, a significant reduction in concentration occurred. Data from the baghouse filter particulate material sample show large concentrations of lead and zinc. Other inorganics were also detected in the baghouse filter material. Volatility of the inorganics at the AER3 operating temperature (3650 °F) is the reason.

Semivolatile organic compounds not observed in either the feedstock or the treated soil samples were observed in the baghouse filter material sample. These results suggest that primary pollutant types of organic compounds recombined during the pyrolysis process, and these organics were released in the exhaust. The baghouse material results indicate that the organic vapors condense on the aerosol particles for collection in the filter. The extent of remaining organic vapors passing on through to the activated carbon filters is unknown because of analytical difficulties with extraction of these compounds from carbon. These results further show the need to be aware of possible recombination of organic compounds in pyrolysis treatment processes, and that there must be adequate protective features in the exhaust stream to preclude release of these

organics to the environment. Also, the baghouse material would need to be appropriately disposed.

Medical examination and exposure monitoring showed that operating personnel were not adversely affected by the AER operation. The medical examination showed no evidence of any toxic material exposure or any ill effects related to the operation. Of two personnel monitoring samples taken near the feed area and the reactor discharge area, no TCDD was detected, with DLVs of 48 and 275 pg/m<sup>3</sup>. Adequate protection was provided for these personnel by using full-face air purifying respirators with appropriate filter cartridges.

## 2. Full-Scale Cost Estimate

With assistance of an engineering contractor experienced in EPA's Superfund activities, a cost estimate of \$14.3 million has been prepared for the excavation, transportation, soil pretreatment, and AER soil treatment of 20,000 tons (18,800 yd<sup>3</sup>) of dioxin-contaminated soil. The NCBC site was used as the reference case. The concept of operation includes environmental controls (soil wetting, closed system soil pretreatment facility, sealed soil storage bins) to mitigate release of contaminants during the process. Planned duration from site setup to teardown is 62 weeks.

Sensitivity analysis of six variables (geographic location, soil quantity, electrical power, labor, capital, and transportation) shows that soil quantity is the dominant factor. By increasing the feedstock rate, reduced cost per ton of soil can be achieved; however, this may cause some system redesign and impact the schedule. The modular compactness of the AER process could be beneficial for transporting and setting up at remote sites, compared to other more bulky, extensive assembled systems such as kilns and their associated air purification equipment. Individual cost estimates have been provided.

An AER with a core of approximately 18 inches was used to model the feedstock rate, which was 30 kg/min. This size of unit is only 50 percent larger than the AER12 large-scale unit, which has been used successfully by Huber in treatment of dioxin- and PCB-contaminated soils. Even though problems were encountered with the small-size AER3, they were readily resolved in the field and would be less sensitive with a larger AER unit, as shown by the experience with AER12.

#### B. RECOMMENDATIONS

1. Based on validation of the Battelle data and use of the CAL data as an indicator of process trends, the Huber AER process should be considered as an acceptable technology for detoxifying dioxin-contaminated soils.
2. The AER process also should be considered as a technology for detoxifying soils contaminated with other organic compounds that require delisting according to EPA regulations.
3. For any full-scale remedial action, the precontract phase should evaluate different soil treatment feed rates to achieve a desired balance on cost and schedule effectiveness by this technology.
4. The use of the AER process should be given careful thought as a method of metal recovery from soils heavily contaminated with inorganics. Characterization of treated soil particles and particles collected from bagfilters by this process is suggested to provide information for metal removal process criteria and cost-benefit analysis.
5. The possible recombination of organic recombination by the pyrolysis process should be further investigated to be fully understood. Meanwhile, any subsequent use of the technology for organic compound destruction should include adequate exhaust

devices to protect the environment. Further, adequate disposal of baghouse filter material likely to contain primary pollutant organics by this phenomenon needs to be factored into the planning (e.g., lengthened residence times, recycle as feedstock, incineration).

6. The acceptability of the AER technology is based on regulations that applied during 1985-86, when the testing and data evaluation occurred. It is recommended that anyone considering use of this technology check the applicable EPA regulations for changes that could impact its use.

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